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MODERN GASWORKS PRACTICE

GIFT OF
MICHAEL REESE

MODERN GASWORKS PRACTICE

MODERN GASWORKS PRACTICE

BY

ALWYNE MEADE, ASSOC.M.INST.C.E.

LECTURER IN GAS ENGINEERING AND ALLIED SUBJECTS TO THE LONDON COUNTY COUNCIL AND AT THE REGENT STREET POLYTECHNIC; MANAGER OF THE WAPPING WORKS OF THE COMMERCIAL GAS COMPANY; MILLER PRIZEMAN OF THE INSTITUTION OF CIVIL ENGINEERS, 1910–11, ETC., ETC

WITH AN INTRODUCTORY NOTE

BY

STANLEY H. JONES, M.INST.C.E., ETC.

ENGINEER AND GENERAL MANAGER OF THE COMMERCIAL GAS COMPANY.

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A. I. E.

INTRODUCTORY NOTE

THE Author has paid me the compliment of asking me to write an introductory note to his book MODERN GASWORKS PRACTICE, and it affords me peculiar pleasure to do so, for I have known him throughout his professional career. He has thrown himself into his subject with characteristic thoroughness, dealing with the works side of gas engineering from alpha to omega, and his treatise will be, I venture to think, a most useful addition to the bookshelves of present-day gas engineers.

The Author's literary work is a fitting sequel to his technical ability and skill as known to and appreciated by one who has had the fullest opportunity of judging—
ἀρχὴ ἄνδρα δείξει.

STANLEY H. JONES.

COMMERCIAL GASWORKS, STEPNEY, E.
November, 1916.

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PREFACE

THE gas industry in this country, in spite of its magnitude, is particularly ill furnished with anything in the nature of a general work of reference dealing with really modern practice. The deficiency, however, can be readily understood when consideration is given to the immensity of the task with which the intending author is faced, the sacrifice of time involved, and, above all, the difficulty of keeping pace with principles and ideas which are in a perpetual state of development. Such prospects, in fact, may well be calculated to damp the enthusiasm of the most determined aspirant.

The author entered with a light heart upon the task of endeavouring to remedy the deficiency, but after twelve months of continuous work, with no prospect of the end in view, " a change came o'er the spirit of my dream," for the enormity of the subject was such that there seemed little hope of ever winning through. However a plunge into the struggle for another few months brought matters to a conclusion, and the present volume, whatever its merits or shortcomings, is put forward in the hope that it may prove of some assistance and, perhaps, enjoyment to the highly trained gas engineer of to-day. It must be realized at the outset that so far as the principles and practice of modern gasmaking are concerned no single individual can lay claim to omniscience, and on no account would the author presume to be especially fitted for the task he has undertaken. No pains have, however, been spared to develop the book essentially on the ideas of the practical man, whilst every precaution has been taken to avoid inaccuracies. In the latter connection the author has taken advantage (perhaps, at so busy a time, too much advantage) of the help of his many friends in the industry, with the result that nearly every chapter has been submitted for suggestions to an expert in the particular branch with which it deals. This assistance, involving as it has in many cases some considerable labour, has been most generously given, and acknowledgment to the full is due to the following gentlemen for their services :—

Mr. G. F. Handel Beard, Mr. F. J. Bradfield, Mr. A. F. Browne, Mr. F. J. Bywater, Professor J. W. Cobb, Dr. H. G. Colman, Mr. E. V. Evans, Mr. G. M. Gill, Mr. Thos. Glover, Mr. W. R. Herring, Mr. Charles Hunt, Mr. Frank H. Jones, Dr. R. Lessing, the late Professor Lewes, Mr. R. J. Milbourne, Mr. Jas. Stelfox, Mr. J. W. Scott, Mr. B. B. Waller, Mr. P. E. Williams, and Mr. Henry Woodall.

In addition, my thanks are due to Mr. Geo. Evetts, Assoc.M.Inst.C.E., who has read through a large portion of my manuscript, and from whom I have received many valuable suggestions. Mr. W. F. Brown voluntarily took upon himself the task of reading through the volume in its entirety, checking all figures, chemical equations,

etc., with the utmost diligence and with great help to myself. Needless to say, the author is nothing without his publishers, and it is not possible to speak too generously of the assistance I have received from this direction, or to express my gratitude too fully for the enterprising manner in which my volume has been put together. I am indebted to the editors of the *Gas World*, the *Journal of Gas Lighting*, and other technical papers, for permission to make use of the material contained in various articles I have written for them.

Finally, I have the gratification of being able to preface my book with a forenote written by Mr. Stanley H. Jones, M.Inst.C.E., chief engineer and general manager to the Commercial Gas Company. In acknowledging this support it may not be out of place to record the fact that the whole of my training in the profession was carried out under his supervision. Consequently, the principles instilled into my mind are largely those of the Commercial Gas Company, principles which, judging from results the world over, are not to be despised.

A. M.

Wapping Works, London, E.
November, 1916.

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MODERN GASWORKS PRACTICE

INTRODUCTION

THE modern gas engineer, beyond realizing that William Murdoch was the first individual to turn coal gas to some practical use, has in many cases a somewhat restricted knowledge of the general historical facts connected with the inception and development of the immense industry to which he belongs. Perhaps, however, this is not surprising when consideration is taken of the multifarious duties and accomplishments now demanded of such toil-worn officials, who, in order to excel, must combine the qualities of engineer, scientist, and administrator, in addition to possessing a specialized knowledge of their primary subject. Under the circumstances it has been thought advisable to trace out briefly the more important links connecting the discovery of destructive distillation with the orderly scientific procedure known to us to-day, in the hope that the reader with a taste for historical incident may find this volume of some small interest and assistance.

The word "Gas" is of somewhat uncertain origin, but in all probability it is derived from the Dutch "geist," meaning "spirit," although some etymologists state good reasons for supposing that the term was initially connected with "chaos." The existence of "fire-damp," which is more or less closely allied to coal gas, appears to have been discovered at a comparatively early date, for Thomas Shirley in 1667 published an extended account of his researches in connection with a burning spring near Wigan. After this there were many similar observations of the production of gas by the decomposition of vegetable matter; but credit for the discovery of destructive distillation most probably lies between the famous Boyle and the Rev. John Clayton, who corresponded in the neighbourhood of the year 1690 on the existence of this phenomenon. It was not, however, until nearly a hundred years after this that serious thought was given to the possibility of utilizing gas as an illuminant. Who was the actual originator of the idea is still a matter for dispute, for several persons seem to have independently conceived the notion at the same time. There was the Belgian, Minckelers; the Frenchman, Phillippe Lebon; and, in this country, Lord Dundonald and Murdoch; but entire credit is usually given to the last-named, who commenced experiments at Redruth, in Cornwall, in 1792. In the same year he distilled a variety of carbonaceous substances, including coal, wood, and peat, and made calculations comparing the cost of light

so obtained with that given by the prevailing illuminants at that time, namely oil and tallow. Five years later he lighted his own premises at Old Cumnock, Ayrshire; whilst in 1802, in celebration of the Peace of Amiens, he arranged for the brilliant illumination of the Soho Works of Boulton & Watt, which firm he had joined.

Attention must now be turned from Murdoch to a man named Winsor, who was attracted by the striking experiments which Lebon was conducting in Paris. Winsor crossed over to France, endeavoured to strike a bargain with Lebon, but failed, and finally returned to England with a full determination to fathom the why and wherefore of the whole business. He studied the subject, mastered it more or less imperfectly, and exploited his invention in Germany. Subsequently he returned to London, and in 1804 gave a series of lectures and exhibitions at the Lyceum Theatre, incidentally raising nearly £50,000 for carrying out his projects. In 1809, he lighted a portion of Pall Mall with gas, this being the first street so dealt with. From then onwards the reputation of the new illuminant was assured, although undertakings existing for its manufacture and distribution had many uphill fights before being established on the road to success. In the same year Murdoch and Winsor came into collision, which resulted in the enterprising plans of the latter being held in abeyance for a time; but 1813 saw the inauguration of the London and Westminster Gas Light and Coke Company, which two years later possessed three manufacturing stations and fifteen miles of street mains. The business of supplying gas progressed with such rapidity that by 1830 more than 200 companies existed throughout the kingdom. Westminster Bridge was first lighted with gas in December 1813, and in the following year the parish of St. Margaret, Westminster. As was only to be expected, the misgivings of the public were at first difficult to quell, whilst profits were non-existent, and the outlook for the future extremely questionable. Soon afterwards the company dispensed with the services of Winsor, who, it is recorded, after his dismissal passed to "the blackness of the tomb in the cemetery of Pére la Chaise, at the age of sixty-seven years."

The history of gas-lighting for the next few years is largely the history of this original company, the now famous Gas Light & Coke Company. The pioneer Clegg (who had left the service of the Company on a question of salary) invented the gas-meter in 1815, although it was not turned to any extensive practical use until ten years later. Meanwhile, the influence of competition was beginning to make itself felt, and it would seem that there was some occasion for it when it is remembered that the price of gas at this time was 15*s*. per 1,000 cubic feet. About 1820 the possibilities of oil gas began to be recognized, and a stout and costly resistance was put up by the London companies to a Bill for the promotion of an oil-gas concern. The Bill was ultimately defeated, but in 1823 Bristol was lit by this product under a special Act. In the same year Sir William Congreve (the Home Office inspector of metropolitan gasworks) issued a report showing that the annual production of gas from the three works of the Gas Light & Coke Company was 248 million cubic feet, whilst they possessed 122 miles of street mains. As years went on a bitter rivalry sprang up between the various manufacturing concerns, and serious

consideration was given to a scheme for the amalgamation of interests. At first nothing came of this, but that things were taking a turn for the better is indicated by the fact that in 1855 the premier company was enabled to make a distribution of 6 per cent. At one time there were no fewer than thirteen companies supplying London, but amalgamation proceeded apace, and to-day the enormous requirements of the metropolis are in the hands of merely three companies. The year 1850 witnessed the introduction by Sir William Perkin of the great aniline industry —since, unhappily, almost entirely lost to Germany; and in 1860 the Metropolis Gas Act came into force.

From then onwards the innumerable concerns which had sprung up in London and the provinces trudged along in a more or less lethargic manner to the accompaniment of increasing profits and abundant dividends. There came, however, a rude awakening in 1883, when the possibilities of electric light were first realized. Shareholders parted with their holdings in apprehension, and the quoted prices of gas stock dropped materially; but far-seeing individuals took the opportunity for increasing their holdings, and soon had cause to be gratified at their wisdom. As it happened, the coming of electricity inspired the renaissance of the gas industry. Seeing that the uses of gas for lighting were likely to undergo restriction, engineers turned their attention to other means of disposal; and the perfection to which countless appliances have been brought to-day is in no small measure due to the stimulating influence of the rival commodity.

CHAPTER I

THE PLANNING AND LAYING OUT OF GASWORKS

INTRODUCTORY

The public supply of gas in this country is governed specifically by many local Acts of Parliament, and in general by the Gasworks Clauses Acts (1847 and 1871), the Sale of Gas Act (1859) and the Gas and Water Works Facilities Acts (1870 and 1873). In addition, London companies are also under the regulations of the Metropolis Gas Act of 1860. A statutory company has powers and obligations under its own special Act or Provisional Order, as well as being governed by the General Acts, which are incorporated therewith as a whole or in part. A Provisional Order may be granted to a non-statutory company under the Gas and Water Works Facilities Acts authorizing the Company to supply gas and conferring the necessary incidental powers. The relation of such a non-statutory company with local authorities and with other statutory companies is similar to that of a statutory company.

Statutory companies and non-statutory companies having powers under Provisional Orders are compelled to supply gas of a prescribed quality within their defined limits of supply, and are usually subject to the infliction of certain penalties if the conditions as to the purity and heating or illuminating power are not complied with. Owing to the extended uses of gas for purposes in which the heating value is of primary importance, Parliament in recent years has, in some cases, substituted a calorific test for the formerly universal illuminating test. For a short period the Gas Light & Coke Company had the dual test, but were relieved of the older test as a result of application to Parliament during Session 1914.

In many cases the price of gas to consumers is graduated on a sliding scale basis, in accordance with which the dividend paid may be increased above a certain standard as the price charged is decreased below an accompanying standard. These two figures are known as the "Standard Price" and "Standard Dividend," and in the case of an increase in price above the standard, the dividend must decrease.

Parliament fixes this standard by a consideration of all circumstances tending to affect the price at which the gas can be produced, plus a margin for contingencies. The accompanying dividend is fixed with regard to the history and position of the company, the considerations as to capital, and the position of the money market at the time of the application.

Many older undertakings are governed by a maximum price and a maximum

dividend. The former method is more satisfactory to consumers and shareholders alike, and is generally adopted, with minor variations, in all new Acts.

In making application to Parliament or the Board of Trade, there are many Standing Orders and Regulations to be complied with. As, however, a Parliamentary Agent must be employed to pilot the Bill or Order through its various stages, the engineer or manager would be advised of all such requirements coming within his (the agent's) province.

A non-statutory company operates as a result of established practice or under the goodwill of the local authority. In opening roads, they may have to obtain the sanction of more than one local authority, *e.g.* for district and main or county roads.

A non-statutory company sometimes supplies gas within the area of a statutory company without molestation. A non-statutory company may set up works by permission in the existing area of a statutory local authority, or if already in possession when a statutory authority proposed to extend its limits, may continue to operate by agreement. Generally, Parliament will respect the rights of a non-statutory company in such circumstances, and will not grant the statutory company the extension of limits unless some such agreement is effected, or unless the non-statutory undertaking were bought out by agreement or arbitration.

Under the Public Health Act of 1875, a local authority outside the Metropolis may become gas supplier. It may purchase an existing undertaking by agreement, or it may set up its own works to supply the whole or part of its district. The latter proceeding may or may not leave another concern supplying a portion or portions of its district. The local authority, in addition to supplying its own ratepayers, often supplies a much wider district. The price charged in outlying districts will in many cases be greater than that prevailing in the inner district, both in the cases of companies and local authorities.

Purchase may be effected by obtaining a "Purchase Clause" in the Bill when the company is applying to Parliament, or by the promotion of a special Bill, which may or may not embody other powers. Parliament does not recognize it as a universal principle that the undertaking should be transferred, and the local authority must bring proof either that there has been serious mismanagement in the past, or that it is to the interest of the ratepayers and consumers that they should be the gas authority.

The price paid for any such transference may be settled by agreement, failing which a price must be fixed by arbitration.

The local authority has similar powers to a company, but has a greater security when raising its capital, *i.e.* the financial backing of the rates; but, unless expressly authorized, it cannot supply outside its own area.

A local authority may include the whole of a neighbouring district in its area of supply, or both areas may be supplied by a Joint Board.

In settling the price paid for transference, the following points are considered, amongst others:—

(1) Amount of maintainable profit, as this is usually the basis on which the concern is bought.

(2) Number of years' purchase.
(3) Profit on fittings, usually capitalized by taking three to five years' purchase.
(4) Whether the undertaking is statutory or non-statutory.
(5) Allowance for surplus or deficient works.

There is no definite rule as to the number of years which are averaged when dealing with the maintainable profit, three or five being common figures. In arriving at the maintainable profit the following considerations vary the amount actually shown as the balance of the Revenue Accounts.

(*a*) Insufficient or excessive repairs and renewals.
(*b*) Working results above or below the normal.
(*c*) Abnormal conditions regarding prices of coal or residuals.
(*d*) Contracts entered into, or rights and privileges affected by transference.
(*e*) Recent scale of growth and prospects.
(*f*) Fairness of price charged for gas.

Goodwill as such is not saleable, although item (*e*) covers claims for future increased profits. The term of years' purchase is dependent on the interest which an investor can get with equal security. The period varies considerably, ranging from ten to thirty years. The seller rightly claims to be put in an equally good position after the sale; in other words, he must earn the same income with the same security.

Anything up to ten per cent. is added for compulsory purchase (where it is compulsory); that is, for interruption of tenure, expense and trouble in seeking new investments, etc., but this is usually a mere matter of form. Claims may be made in deductions from the total arrived at for immediate necessary expenditure to maintain the profit, or to keep the undertaking in a good position generally. The structural valuation of the undertaking has little bearing on the price paid, and is estimated in order to indicate the capital assets of the concern.

It should be mentioned that in addition to the General Acts named at the beginning of this chapter, the sale of gas in Scotland is governed by the Gas Acts (1864), and the Burghs Gas Supply Acts (1876 and 1893).

The supply of gas in Scotland is very largely in the hands of the local authorities, and in England the counties of Yorkshire, Lancashire and the North generally are much more marked in this respect than the Home and Southern Counties. Whether in the hands of companies or of municipal authorities, however, the industry as a whole is remarkably well managed, and is on a firmer basis now than ever before in its history. Gas for all purposes has ceased to be a convenience, and has become a necessity.

THE CHOICE OF A SITE

The first preliminary to the erection of a gasworks is the selection of a suitable site. Although this task may appear to be one of extreme simplicity, this is by no means the case, and hasty consideration of the matter may have a lasting

influence on the welfare of the undertaking. The more important points to be kept in view may be summarized as follows :—

(*a*) Ready access to sea, river, canal or railway. Cartage to and from the works should, as a general principle, be avoided as far as possible, and works having a combination of water, rail and road facilities enjoy an enviable position. This accessibility has a twofold value, viz. : in getting coal and other materials into the works and in the taking away of residuals. Generally, it may be taken that good sea or river access is preferable to rail.

With reference to the last mentioned, the actual construction of sidings is a financial matter, depending entirely on the money to be saved balanced against the annual charges for construction, working and incidental costs payable to the railway company.

(*b*) The level of the ground should be low in comparison with the districts to be supplied. It is a " golden rule " of gas engineering never to erect a gasworks on a hill. Owing to its specific gravity (0·42 to 0·52, depending on the proportion of carburetted water gas), gas exerts its pressure in an upward direction ; hence where the works is erected on elevated ground unnecessary pressure has to be sacrificed in driving the gas downwards to consumers. With regard to the so-called loss in pressure, this amounts approximately to 1 inch of water for every 100 feet rise in elevation. There are generally, of necessity, many points lower than the gasworks, especially in undulating country, but in general, keep low, having regard to other matters mentioned later with reference to flooding.

(*c*) The character of the surrounding property must be considered. A gasworks is essentially a thing of utility, and can lay little claim to aestheticism ; therefore the picturesque portions of the district should be respected. For the same reason, a site should not be chosen in the fashionable quarter of the town, otherwise complaints from well-to-do residents will be a continual source of annoyance.

Here it may be mentioned that when applying for parliamentary sanction to make or purify gas on any land, notices have to be served on all owners, lessees and occupiers of dwelling houses within 300 yards of any portion of the said land, who may petition the House (before Committee) against the adoption of the site.

(*d*) The ground should be suitable for foundations, both as to cost and stability. Before a definite agreement is concluded, trial borings should be made, and the nature of the subsoil determined. Hard gravel, ballast and chalk are the ideal. Many clays form excellent foundations, whilst " made up " ground (such as disused rubbish heaps, tips, etc.) is probably the most treacherous. Running sand, compressible clays, soft peat and fine alluvial soil may turn out to be very untrustworthy and costly. Rock, of course, makes excellent foundations, but is expensive to work, although it may be used for concrete mixing. Further economy may be effected by obtaining sand or ballast from the ground.

Of extreme importance is the permanent water level, and the possible floods level ; both affect the cost of works construction, the former in particular. The latter affects the actual operation of the works, for no gasworks can be called satis-

factory if always liable to floods. The loss of tar and liquor from underground wells would be considerable and the damage to buildings and plant would be heavy, but the greatest danger would be that of complete stoppage by the extinguishing of furnaces in the retort house. These points are more fully dealt with in Chapter II (Foundations).

A plentiful supply of water under control is, of course, an economic asset, effecting a considerable annual saving.

(*e*) The distance of the site from the centre of the area of greatest consumption is a further point. The works need not necessarily be erected within its own limits of supply, although it almost invariably is. Owing to high cost of land near the centre of towns, the gasworks is usually situated on the outskirts, or what were the outskirts when the works was erected. In such cases, of course, the additional length of trunk mains must be balanced against the saving in cost of land, and the sale of residuals and cartage costs must in general be considered. For long distance transmission, modern methods by means of "boosters" may be employed, permitting the use of smaller and therefore cheaper trunk mains. Needless to say, the high pressure must be governed down for ordinary purposes. It often happens (after considerable growth) that storage plant has to be erected further out of the town, so that the central site may be occupied for manufacture and purification. A minor factor requiring consideration is the possible danger of pollution to the water supply by percolation, particularly in chalky districts.

CONSIDERATIONS AFFECTING SIZE OF WORKS

Before much headway can be made with the actual definition of the site boundaries, some idea as to the extent of the ground required must be arrived at, this, of course, being dependent upon the quantity of gas likely to be consumed immediately and during the next fifteen or twenty years. It is as well to be generous in the purchase of land, particularly if it is cheap; and preference should be given to a site which is capable of extension. A square or rectangular site is the most suitable for laying out buildings and plant.

As regards the quantity of land to be purchased, experience is really the only reliable guide; so much depends upon the nature of the district to be supplied, whether residential or manufacturing, the class of inhabitant, presence or absence of electrical competition, and the price at which gas is intended to be sold. In this respect sales of gas, unlike water, cannot be satisfactorily calculated by an allowance of so much per head of population; for, although every individual may be credited with a desire for water, the same cannot always be said of gas. As a matter of fact, in the larger cities the average consumption per head per annum is from 5,500 to 10,000 cubic feet, whilst in the smaller towns it may be from 3,000 to 7,500 cubic feet. Fifteen years ago it was a general rule to base the former at 2,000 cubic feet per head and the latter at 1,600 cubic feet.

The table will give some idea as to how matters stood prior to the European war:—

	Cubic feet per head.	Cubic feet per consumer.	Sale in millions per annum.	Price.
				s. *d.*
Birmingham	10,200	47,500	9,156	1 11 less 5%*
Manchester	7,200	27,200	5,659	2 2 „ 2*d.* *
Nottingham	7,600	26,000	2,169	2 2
Leeds	6,100	20,900	2,723	2 2 less 5%*
York	5,800	23,200	540	2 1
Brighton	7,700	31,000	1,450	2 10
Hastings	5,600	34,800	475	2 10½
Guildford	7,200	30,200	195	2 8
Watford	5,700	26,800	291	2 8
Canterbury	5,700	25,200	150	2 8
Longwood	4,600	19,000	130	2 5

* Discount applied to accounts paid within one month.

From an estimating standpoint, the second column of figures is the most useful, for, taking all considerations into account, the number of consumers and their average can be fairly closely approached by anyone of experience. The figure in the column referred to includes public lighting, treating each lamp as a consumer. In the general way, a very good idea of the total probable output can be gleaned from an analysis of the situation on lines such as the following :—

Suppose that the town to be supplied consists of a middle class and normal residential population (seaside resorts have to take into account the summer influx of visitors) with trades and industries of its own. For the sake of example, assume a normal population of 90,000, then with gas at a moderately low price, about 17½ per cent. of the population may be expected as consumers, made up as follows :—

Say 17,500 to 18,500 houses, of which the mains to be laid would permit of access to 17,000 or so. In the circumstances, 90 per cent. of these may be expected, or 15,500.

Then the estimated amount of gas to be sold per annum would be :—

	Cubic Feet. Millions.
6,500 consumers through ordinary meters at 42,000	273
8,500 „ „ "slot" „ 15,000	127
For industrial purposes extra (say 500 consumers)	60
For public lighting (1,200–1,500 lamps)	20
	480

In addition to this sale, about 6 per cent. must be allowed for gas lost by leakage and gas used on the works. This brings the annual production up to 508 millions, or, in round figures, 500 millions. The sale per head then works out at nearly 5,500 cubic feet, or 30,000 cubic feet per consumer, excluding public lighting; which, on reference to the table, is seen to be normal, and satisfactory for estimating purposes.

AMOUNT OF LAND REQUIRED

In considering ground area required, much depends on the manufacturing system it is proposed to employ, but a good guide is to allow a minimum of 2 acres per million cubic feet per diem. So far as the maximum day's send out is concerned, this is now found to amount to 1/220 or 1/230 of the whole year's consumption. That is in normal cases, apart from health resorts or towns having a double heavy season.

Ten years ago this ratio varied from 1/185 to 1/210; so that it is now possible to sell from 10 to 15 per cent. more gas with identical plant, owing to the levelling up of the daily load curve. In the same manner the hourly load curve has also been appreciably straightened out, thus saving many undertakings considerable expense in gasholder construction.

In the example taken we get a maximum day's production of 500/220 millions per day = 2·3 millions. So that land and plant must be at least equal to this production.

Land required = $2{\cdot}3 \times 2 = 4{\cdot}6$, say 5 acres. More than this is needed if the works is to be planned with a view to easy and economical extension, a point of great importance in the works design. Also, more land generally means greater economy in working. It is interesting to note that twenty years ago the late Mr. A. Colson expressed the view that 2½ acres were required per million per day as a minimum. Since then, however, the gas-producing capacity of a given area has considerably increased, although the remainder of the plant (except gasholders) has undergone very little change so far as necessary ground space is concerned.

CAPITAL EXPENDITURE

The capital expenditure likely to be entailed in the erection of a gasworks and the equipment of the district is difficult to compute with any degree of accuracy until the site is selected and preliminary survey and estimates have been made. So much depends on the prevailing value of materials of construction, the requirements of labour, the geographical position of the town, facilities for conveying materials to the site, etc., that no hard and fast rule, applicable to all cases, can be given.

In preliminary estimates, for parliamentary and other purposes, it is advisable to allow a fair margin to cover possible increases in cost, as the work may be carried out as long as two years after the preparation of the estimate.

In general, however, a concern promoted for the erection of a modern works, and for providing the distribution plant necessary to sell the gas, should find it possible to complete the scheme for £600 per million cubic feet sold per annum, *i.e.* 12*s.* per thousand cubic feet sold per annum. In the case of the larger works, the figure may be reduced to £550 or less, but for the smaller country works the outlay will usually be considerably greater, a normal figure being as much as £750 to £1,000 per million cubic feet sold, according to size.

Capital expenditure based on output in this manner should, with proper management, decrease as years go on, chiefly due to the taking up of increased business

with existing plant, or by only slight additional expense for considerably augmented consumption. A judicious expenditure out of revenue to increase the efficiency of the plant and mains is an aid to this desirable end; for it must be borne in mind that capital expenditure is usually the very crux of a company's condition. In nine cases out of ten, the capital charge to be met is the heaviest item (proportionally) in the revenue account.

As an example of this tendency, and the improvement effected by expansion of business, the average capital expenditure by the three metropolitan companies was :—

In June, 1906	11*s.* 2*d.* per thousand cubic feet sold.
In „ 1910	10*s.* 9*d.* „ „ „ „ „
In „ 1912	10*s.* 2*d.* „ „ „ „ „
In Dec., 1913	10*s.* 1*d.* „ „ „ „ „

The following figures give an indication of this item, and its relation to various companies and corporations :—

(All figures relate to the period just prior to the European war.)

	£ Per million cubic feet sold per annum.	Shillings per thousand cubic feet sold per annum.
COMPANIES.	£	*s.* *d.*
Gas Light and Coke	546	10 11
South Metropolitan	387	7 9
Brighton	462	9 3
Derby	479	9 7
Bath	362	7 5
Hastings	862	17 3
Newcastle	759	15 2
Sutton	454	9 1
Watford	487	9 9
Reading	483	9 8
Longwood	660	13 3
CORPORATIONS.		
Birmingham	283	5 8
Manchester	525	10 6
Leeds	692	13 10
Nottingham	546	10 11
Leicester	638	12 9

In recent years the capital expenditure on the district has increased rapidly, owing to the development of the prepayment meter business and the greatly extended use of gas cookers, fires, geysers, etc. The first-named item of expense is considered as varying from £3 10*s.* to £5 10*s.* per house (including cooker), but excluding service, which is common to all classes of consumer. The consumption for this expense may be from 7,000 to 22,000 cubic feet per annum; and, averaging these

figures, we get an expenditure of £310 per million on the gas sold through this channel. There is, of course, an increased receipt from this source, which may or may not give an adequate return on the capital, after allowing for extra cost of collection, repairs, and maintenance.

The result is that, whereas twenty years ago the works usually cost more than the distributing plant, the reverse is now invariably the case. Keeping in mind, however, the general example we are considering, the cost of mains, meters, stoves, etc., comprising the distributing plant, may absorb 55 per cent. of the total, the works and equipment amounting to 38 per cent., whilst engineers' fees, parliamentary and promotion expenses complete the total. A fact not generally realized with regard to works outlay is that the expense of gasholders in many cases accounts for one-fourth or even one-third of the total, and is the most expensive individual item on the works. The remainder is apportioned somewhat as follows :—

Land	2–4 per cent. of works expenditure.
Carbonizing plant (including buildings)	20–27½ „ „ „ „
Purifying plant	5–8 „ „ „ „
Exhausters, condensers, washers, etc.	3–4 „ „ „ „

GENERAL RULES FOR SIZE AND CAPACITY OF PLANT

Gasworks are never designed by rule-of-thumb methods, and the details connected with their construction are mostly the outcome of extended practical experience. For all that, certain constants for the computation of the capacity of the various pieces of plant have come to be recognized, and are given here with the strict warning that they are merely a guide, exemplifying rules and their application. Varying circumstances alter cases, and in laying out the works all those circumstances should be taken into account which would tend to vary sizes from the normal. Although, in the main, the rules given will be found as occurring in general practice, the author wishes to deter the aspiring designer, with little or no actual experience of gasworks erection, from drawing up specifications on such a basis alone.

Land

Allow at least 2 acres per million cubic feet per maximum day.

Retort House

Dependent upon the gas-making capacity of each "unit," *i.e.* the batch, of retorts set in each arch. The following table gives approximate figures for the make per retort per day of twenty-four hours :—

Stop-ended retorts, 9 feet to 10 feet long × 15 inches round	3,000–4,000 cubic feet.
„ „ 10 feet long × 16 inches round	4,000–5,500 „ „
„ „ 10 feet long × 21 inches × 15 inches ▭ or 10 feet long × 22 inches × 16 inches ▭	7,000–8,500 „ „
"Through" retorts, 20 feet long × 24 inches × 16 inches ▭	18,000–20,000 „ „
Vertical retorts, Woodall-Duckham type	60,000 „ „
„ „ Glover-West type	36,000 „ „
„ „ Intermittent (Dessau) type (5 metres long)	15,600 „ „

Instead of speaking of the make per retort per diem, it is usual among gas engineers to work on a basis of " make per mouthpiece " per diem. This is particularly the case with horizontal and inclined retorts; thus the " make per mouthpiece " for a stop-ended retort would be 3,000 to 8,500 cubic feet, the same as the make per retort. For a " through " retort it varies from about 7,500 to 10,000 cubic feet, *i.e.* half the make per retort, this being due to the fact that the retort has two mouthpieces—one at each end.

Coal Storage

It is customary, and it has been found advantageous, to provide for storage under cover sufficient for twenty-one maximum days' production. In recent years, owing to the unsettled condition of the labour market, the larger companies have in many cases sufficient supplies for their needs for three months; hence recourse has to be had to stacking large heaps out in the open. No undertaking can now afford to risk three weeks' storage, although this is still a common and sufficient allowance for that kept under cover. The calculation of the cubical capacity required for storing a definite quantity of coal may be closely arrived at by assuming that 1 ton of average gas coal occupies 42 to 43 cubic feet of space. One ton of gas coke requires a space of about 85 cubic feet. Coal should not be stacked to a greater depth than 20 feet, owing to the danger of spontaneous combustion.

Condensers

Owing to the many advantages attendant upon the use of water condensers, they are now frequently employed in preference to the original atmospheric type; the latter, however, are still used in small and medium-sized works, and are not without their good points. It should be remembered that the initial stages of condensation should be effected slowly.

There are several rules for the capacity of air condensers, and the variable nature of the results they give shows that engineers are by no means agreed on the subject. A common and reliable rule is the following:—

Allow 5 square feet of atmospheric condensing surface per 1,000 cubic feet of gas made per day (maximum day's production to be taken). This area includes all pipe from the outlet of the hydraulic main to the outlet of the condenser, and permits of a small deduction being made if there is a further long distance to the inlet of the exhauster. Various authorities recommend increasing surfaces up to nearly double this amount.

Regarding water-cooled condensers, there is considerable variation, according to type, amount and speed of water circulation, etc., but for general purposes about 3 square feet per 1,000 cubic feet per day should be allowed, *i.e.* about one-half of that necessary with the atmospheric type.

Exhausters

Except on very small works, say less than 10 or 12 millions, the exhausting plant is generally laid down in duplicate, to allow of repairs or adjustments to one

set. A useful combination for medium-sized works is one set equal to the maximum winter's production and the second equal to that of the summer. It should be remembered that the cost price of exhausting machinery increases at an appreciably slower rate than capacity; hence it is often convenient, and in a growing place absolutely necessary, to lay down exhausters in excess of immediate requirements. Slower running of an under-taxed exhauster will always make for smoother work and longer life.

In a works of 4 to 6 millions per annum the saving to be effected in purchasing an exhauster is problematical, after paying interest on capital and running costs. For works over 6 millions the buyer is on safe ground, and in such works (say less than 15–20 millions) it is usual to drive by gas engine, which provides power for operating tar, liquor and other pumps. If working to exact capacities, it is merely necessary to take a very small margin over the maximum day's production, which is arrived at by dividing the yearly production by 220. The maximum day divided by 20 or 22 will give the maximum hour, which is the usual way of tabulating exhauster capacities. The effective hourly capacity of an exhauster is guaranteed by the makers, and reference to catalogues gives all particulars relating to standard sizes, space occupied, etc.

For the capacity of a four-blade exhauster, the following formula may be taken; it is not, however, recommended when dealing with very large (over 4 feet) or very small exhausters:—

$$Q = 65\ D^2\ L.N.$$

Where Q = cubic feet passed by exhauster per hour.
D = inside diameter of outer drum in feet.
L = length of drum in feet.
N = number of revolutions per minute.

About 20 per cent. of the amount arrived at must then be deducted for "slip."

The power necessary to drive exhausters is dependent on their capacity and the total back pressure to be overcome. (See Chapter XIII.) This necessary power at the shaft needs a little more at the engine, the extra being dependent on the method of driving, whether direct coupled or through shafting.

Generally, however, the maker has a standard engine to a certain sized exhauster, leaving sufficient margin, and unless stated otherwise by the purchaser, this standard size will be supplied.

Wet Purification Plant

This may include one, two, or three of the following types of plant:—

Tower scrubber.
Livesey type washer.
Mechanical washer.
Washer-scrubber.
Purifying machine.

The last mentioned includes one or two makes of mechanical apparatus which

remove both tar and ammonia. The washer-scrubber is mechanical, and the many different patterns conform to one general type. Livesey washers, made by many firms, are not mechanical; and the first mentioned in the list is usually fed with water or liquor by mechanical means. In many cases two pieces of plant in the above list are associated with a tar extractor of the Pelouze pattern. By far the most common combination is a mechanical washer-scrubber followed by one or more tower scrubbers. If two are adopted, the last is fed with clean water, which should, if desired, remove the whole of the ammonia.

In small works, it is common to have only one or two tower scrubbers, with no mechanical washing apparatus whatever. When associated with a mechanical apparatus, the scrubber allowance should be at least equal to 5 or 6 cubic feet per 1,000 cubic feet of gas per day. Newbigging and Herring recommend 9 cubic feet. In cases where no washer-scrubber is employed, the aggregate capacity of ordinary washers and scrubbers must be increased to 10 cubic feet per 1,000. In very small works where only one tower scrubber is used, this figure might with advantage be increased to 12 cubic feet. The ratio of the height of a scrubber to its diameter varies in normal cases from $2\frac{1}{2}$ to 5.

With regard to the other forms of apparatus mentioned, each manufacturer has his own standard sizes of plates for varying capacities, but as a general guide the following figures will be found useful:—

Livesey washers	$\frac{1}{7}$–$\frac{1}{5}$ cubic feet per 1,000 cubic feet per day.
Washer-scrubbers	$\frac{1}{3}$–$\frac{3}{4}$ " " " " " " " "

Dry Purification Plant

If it is necessary or desirable to remove sulphur compounds other than sulphuretted hydrogen, the purifier capacity is increased, this usually calling for the use of lime in addition to oxide of iron (or its equivalent). Under such circumstances it is advisable to increase slightly the size of the vessels, as well as further increasing the capacity by means of catch boxes. It should be remembered that if more area can be given than in the following rules, it is never wasteful, purification charges undergoing reduction, whilst the first cost of the plant increases slowly as compared with the capacity. In other words, the smaller the boxes the more expensive do they become per unit of purifying capacity. For oxide purification only (for a set of four purifiers) an area of 0·5 square faat per 1,000 cubic feet per day should be provided as a minimum in each box. If lime is used this figure should be increased to 0·6 square foot, or to 0·65–0·7 if no catch boxes are provided. For the total amount of purification space necessary (*i.e.* the combined area of all boxes) the rule given by Hunt is useful. This states that for lime and oxide purification 20 to 30 square feet per ton of coal carbonized per day should be allowed.

A further rule, based on the amount of oxide in the boxes, is that one ton of oxide may be expected to purify about 2 million cubic feet of gas before becoming finally spent.

The maximum figure can only be obtained when air is put into the boxes for

revivification. A further rule is that for each 1,000 cubic feet of gas per day allow 1½ to 2 cwts. of oxide in each of four boxes.

In designing plant for a growing works, it is necessary to provide for the more or less immediate future, and it is advisable to erect only three boxes, making provision for the easy addition of the fourth. In this case the boxes in the set of three should be made 50 or 60 per cent. larger than those necessary in a set of four (say 0·8–0·85 square foot per 1,000 cubic feet per day for the area of each box). In the case of a very small works with prospect of growth, two boxes with facilities for extension can be put in with advantage, in which case each box should be made 3–3½ times as large as if there were four (1·5 to 1·7 square feet per box per 1,000 cubic feet per day). By adopting this plan the first cost is not increased, and money is saved when extensions are carried out.

The size of connections for purifiers may be calculated as follows :—

$$\left.\begin{matrix}\text{Diameter of pipes} \\ \text{in inches}\end{matrix}\right\} = \sqrt{\text{Area of each box in square feet.}}$$

For small purifiers make no deduction from the figure so found, but in large and medium sized boxes deduct $\frac{1}{6}$ to $\frac{1}{4}$.

Small boxes are from 3 to 4 feet deep, and large ones may run from 6 to 8 feet, 6 feet being most common. The intermediate sizes vary from 4 to 6 feet in depth. Purifiers vary in size from 12 square feet in area up to 40 feet square, the latter size being suitable for a 2¾ to 3 million cubic feet a day unit. For constructional reasons, convenience in working, lifting covers, emptying, etc., when the works is larger than this it becomes necessary to divide the gas into streams, each with its own set of boxes. In works making less than 2¾ to 3 millions per day this system is also in operation owing to development in the past, and it is very useful where different sized units are in use, the larger set being operated in summer and both sets in winter.

Thus a 3 million a day works would have 35 or 36 feet boxes for its larger unit and 24 feet boxes for the smaller unit. The former unit would probably be sufficient for eight months in the year, and both sets would be in use for the remaining four months. The larger set would then take 27-inch connections and the smaller 18-inch to 20-inch.

For carburetted water-gas purifiers it is advisable to take 0·8 square foot per 1,000 cubic feet per day for each box, again assuming four boxes to the set.

Governors

Dependent entirely on the nature and conditions of the district to be supplied. Absolutely no rules can be given attempting to cover more than the simplest possible case, *i.e.* a level district, with the gas sold in one centre, in which instance the one necessary governor is of the same size as the main outlet pipe from the works.

Storage Capacity

The levelling up of the hourly load curve in recent years has had a marked effect on the amount of storage necessary. In spite of considerable increases in annual

sales, none of the three metropolitan companies has built a gasholder for many years, and as the South Metropolitan Company is here included, the question of storage cannot be due entirely to the use of carburetted water gas, although it is naturally influenced by the presence and capacity of the water-gas plant. The other factor affecting the storage required is the nature of the supply, whether chiefly lighting, or power, or cooking; the last two, if in large quantities, causing the peak to be from 11.30 a.m. to 1.30 p.m., or thereabouts, instead of during the evening.

Where the load curve is assisted in this manner and surplus water gas is available, the storage can safely be reduced to 18 hours' maximum make. Otherwise 21–24 hours' should be provided for. It is as well not to rely on the surplus water-gas plant other than as a means for meeting emergencies, such as fogs or breakdown in coal-gas plant. With reference to ground space occupied, it may be mentioned that gasholders require, roughly, 20 per cent. more room than the combined retort houses and coal stores, under normal conditions.

It will be understood that the storage capacity on the daily make basis is very elastic, as the newest holder is almost invariably the largest; consequently before this is put into operation the storage is deficient, whilst immediately afterwards it may be excessive, provision being made for the future.

A common method of providing for future development is to build the tank and one or more lifts with all arrangements for adding a further (outer) lift in the future. Thus the capacity of such a holder may be increased from 50 to 100 per cent. with a comparatively small expenditure. It must be remembered, however, that this method cannot be adopted where one holder is relied upon, or where the other storage is so small that it cannot be reduced even in the slackest season of the year; for the holder must necessarily be out of action for some weeks during the alterations. Albeit, many undertakings have gone through this ordeal on 12 hours' storage, even when based on the minimum day (8–9 hours of maximum day).

The proportions of gasholders are discussed in Chapter XVII, but for single lift holders allow height equal to 0·3 to 0·4 of the diameter, and for multiple lift holders 0·6 to 1·0 of the diameter. This excludes tanks in both cases.

Tar and Liquor Storage

A good tar storage is advisable, as it assists the manager in times of low prices, in addition to which the sale is a fluctuating one.

If the works manufacture its own sulphate, it is advisable not to store ammoniacal liquor for too long, owing to evaporation and other losses. A general guide is 5 weeks' (maximum) storage for tar and liquor.

Sulphate Plant

Assuming that sulphate is made ten or twelve times a year, the plant should have a capacity of 3–3½ tons of sulphate per 24 hours for every million cubic feet of gas per maximum day. This allows for sulphate making during six days. If it is proposed to make at different periods, or for more or less days, the adjustments can be made accordingly.

Works Mains

It is difficult to give definite rules, but the following will form a rough guide, based on particulars of many works :—

Mains	5	inches	diameter	suitable	for	works of	3	to	4	million	cubic	feet	per	annum.
„	6	„	„	„	„	„	6	„	10	„	„	„	„	„
„	8	„	„	„	„	„	15	„	25	„	„	„	„	„
„	10	„	„	„	„	„	30	„	45	„	„	„	„	„
„	12	„	„	„	„	„	55	„	90	„	„	„	„	„
„	15	„	„	„	„	„	100	„	150	„	„	„	„	„
„	18	„	„	„	„	„	200	„	300	„	„	„	„	„
„	20–21	„	„	„	„	„	350	„	450	„	„	„	„	„
„	24	„	„	„	„	„	500	„	600	„	„	„	„	„
„	30	„	„	„	„	„	600	„	900	„	„	„	„	„

GENERAL NOTES ON THE LAYING-OUT OF WORKS

Having decided upon the sizes of buildings and plant, the engineer's next task is that of setting these out on the site at his disposal. Each site will have its own particular conditions, but the following points may be taken as applicable to all circumstances.

The retort-house and coal stores should be adjacent to the point of coal intake; and, in laying-out, the disposal of coke must also be kept in mind. If possible, arrange for the coal storage which is not under cover to be also convenient for the retort-house, and allow plenty of room for coke storage, and for pulling up carts, etc. High coke tips should be avoided, as they are expensive and give rise to excessive quantities of breeze. The coal and coke handling should be quite separate (on opposite sides of the building, if possible); and, if the site is not being filled up at once, room should be left for enlarging without undue destruction. Provision should be made for any items of extension which may be contemplated. The site should be laid out for what it is comfortably capable of, so that each piece of plant may have room for extension up to that limit. Cartage ways and other means of access must, if possible, be left around all buildings.

Boilers should be central for feeding exhausters, mechanical washers, sulphate plant, pumps, etc.; whereas gasholders should be kept on the side towards the populated parts, thus partly shielding the works, with the purifiers and sulphate plant far away from entrance gates and roads. Plenty of room should be left near the purifiers for laying out oxide, a generous portion of this being under cover. A point which is often overlooked is that of keeping the gasholders as far as possible from the causes of corrosion, such as the water-gas plant, chimneys, sulphate plant, etc.; whilst purifiers should be some distance from the boiler houses. The ideal place for scrubbing plant, in fact all plant for the extraction of tar and ammonia, is next to the storage wells—thus avoiding long distances for pumping. It is scarcely necessary to add the warning that all underground tanks should be kept out of the line of heavy traffic.

ESTIMATED COST FOR A 500-MILLION WORKS

In drawing up specifications for a gasworks of some definite capacity it is invariably the practice to put down apparatus of a sufficient size to take up future requirements.

In the following estimate, however, this has not been done, for it is desired to show the reasonable cost of producing and distributing about 500 million cubic feet per annum—the expenditure on a works having its apparatus designed with a view to dealing with an output of an additional 20–40 per cent. cannot be taken as exemplifying the minimum outlay. For this reason the figures will probably be considered by some as being on the low side.

It is assumed that about 20 per cent. of carburetted water gas will be made, on the average. All costs include foundations, and relate to the normal conditions prior to the European war.

		£	£ per mouthpiece.	£ per ton of coal per max. day.
LAND	1 acre per 100 millions per annum, or 2 acres per million per diem. 5 acres at £700.	3,500	13·4	23·3
HORIZONTAL RETORT BENCH FOUNDATIONS, FLOORING, ALL IRONWORK AND ACCESSORIES	Settings of "tens" suitable, 20 feet retorts (*i.e.* five tiers of two) as occupying least ground space. Assume "make per mouthpiece" 8,500 cubic feet per diem, machine charging. Required make (maximum per day) $= \frac{\text{annual make}}{220} = 2\frac{1}{4}$ million cubic feet. Less 20 per cent. for water gas, 1,800,000 cubic feet of coal gas per diem. Make per setting $8{,}500 \times 20 = 170{,}000$ cubic feet. No. of settings required $\frac{1{,}800{,}000}{170{,}000}$, say 10 or 11. In addition 20 per cent. should be allowed for retorts "scurfing" or otherwise out of action, bringing the total number of beds up to 13.			
	Carried forward	£3,500	13·4	23·3

		£	£ per mouthpiece.	£ per ton of coal per max. day.
	Brought forward	3,500	13·4	23·3
	Average cost, including foundations and accessories, chimney, etc., £50 per mouthpiece, *i.e.* 260 × 50. .	13,000	50	*86·7
Retort House and Coal Store	Capacity in cubic feet required for 13 settings.			
	Length.—Each setting 9 feet 6 inches + 12½ per cent. for passages, outside walls, etc. = 140 feet.			
	Width.—Assume projector charging from one side only.			
	ft.			
	Width of bench 20			
	Floor space. Charging side. . 23			
	,, ,, Discharging side 17			
	Total 60			
Coal Storage .	Three weeks' storage under cover. Max. day's coal consumption $= \frac{1,800,000}{12,000} = 150$ tons.			
	Three weeks' storage 150 × 21 = 3,150 tons.			
	Coal will occupy 3,150 × 42 = 132,300 cubic feet.			
	Depth must not exceed 20 feet, preferably 16 feet. Length of house is 140 feet. Then required width for coal store (if coal stacked 16 feet deep) to give this capacity = 59 feet, say 60 feet.			
	Total effective width of house			
	ft.			
	= 60 + 60 = ... 120			
	Add for division walls . . 2			
	Total internal width . . 122			
	Carried forward	£16,500	63·4	110·0

		£	£ per mouth-piece.	£ per ton of coal per max. day.
	Brought forward	16,500	63·4	110·0
	Height.—Dependent upon type of house. Stage house most suitable. Height, ground level to working stage . . . . ft. 9 in. 6 Height, working stage to top of settings . . . . . 15 0 Height, additional headroom for continuous hoppers, coal conveyors, etc. . . 16 6 Total to eaves 41 0			
	Rise of roof about ¼ of span $\frac{60}{4} = 15$ feet.			
	Internal Capacity.—140 feet long × 122 feet wide × 48 feet high (this is mean height of building to half-way up roof) = 820,000 cubic feet. Assume a steel-framed, brick-panelled structure at 2¾*d.* per cubic foot (including foundations)	9,400	36·2	*62·7
	**Note.*—Owing to the excess retort capacity allowed, the figures given (£86·7 and £62·7) for complete cost of retort house would naturally undergo some reduction if full carbonizing capacity was made use of.			
COAL ELEVATORS.	Breakers, conveyors, breaker pits, overhead hoppers, coke trucks, rails, etc.			
	In this case average cost per mouth-piece for above would be £12. 260 mouthpieces at £12	3,120	12·0	20·8
	N.B.—Coke conveyors would be in addition to this, say £3 to £4 per			
	Carried forward	£29,020	111·6	193·5

		£	£ per mouthpiece.	£ per ton of coal per max. day.
	Brought forward	29,020	111·6	193·5
	foot, or an additional cost of £800 to £1,000, according to length. Projector, pusher, trolley wire, cabling and accessories	1,700	6·5	11·4
POWER PLANT .	Gas engines, dynamos switchboard, cabling and all accessories. In this case average cost per mouthpiece £5 to £6	1,430	5·5	9·5
CONDENSERS. .	Max. hourly make $= \frac{\text{daily make}}{22} = \frac{1,800,000}{22} = 82,000$ cubic feet per hour. Two water-tube condensers to take 40,000 to 50,000 cubic feet per hour each, fitted complete	1,000	3·8	6·7
EXHAUSTERS. .	One at 80,000–100,000 cubic feet per hour. Two at 40,000 cubic feet per hour. Engine of about 10 h.p. required for large exhauster, 6 h.p. for smaller one. (Note that this plant is put down in duplicate)	1,100	4·2	7·4
WASHER SCRUBBER	Say vertical centrifugal type to take 80,000 to 90,000 cubic feet per hour. Complete with engine and bevel gear drive	800	3·1	5·3
TOWER SCRUBBERS	Total capacity on basis of 6 cubic feet per 1,000 cubic feet of gas per diem. $1,800 \times 6 = 10,800$ cubic feet. Two scrubbers each 40 feet high by 14 feet diameter would be suitable, thus giving 6,000 cubic feet for each vessel; an allowance 10 per cent. in excess of the minimum. . .	1,900	7·3	12·7
	Carried forward	£36,950	142·0	246·5

		£	£ per mouth-piece.	£ per ton of coal per max. day.
	Brought forward	36,950	142·0	246·5
DRY PURIFICATION PLANT	Assume that oxide only is to be used. Then a set of four purifiers at the minimum allowance, worked in rotation, with two small catch boxes would suffice. Area required for each box 0·5 square foot per 1,000 cubic feet per diem. 1,800×0·5 =900 square feet, *i.e.* boxes 30 feet square by 6 feet deep. Size of connections as per rule on later page 16, $\sqrt{900} - \frac{1}{5} = 30$ less $\frac{1}{5} = 30-6 = 24$ inches. Total plant—complete with all valves, lifting gear, etc.	4,600	17·7	30·7
STATION METER .	To pass 85,000–90,000 cubic feet per hour, 24 inch connexions . .	1,000	3·8	6·7
STORAGE . . .	One holder (in addition to water-gas relief holder) is here assumed, although if the works had grown from small beginnings there would be more. As the works has a water-gas plant, 18 hours' storage should be ample. Total make (water gas and coal gas) 2¼ million cubic feet per diem. 18 hours' storage 1¾ million cubic feet. Telescopic gasholder, with guide framing and tank (brick and puddle). Approximate cost £11 10*s.* per 1,000 cubic feet	20,000	76·9	133·3
GOVERNORS . .	Dependent upon system of distribution employed, but assuming three in operation	360	1·4	2·4
PUMPS . . .	Liquor, tar and water.	250	1·0	1·7
	Carried forward	£63,160	242·8	421·3

		£	£ per mouth-piece.	£ per ton of coal per max. day.
	Brought forward	63,160	242·8	421·3
STEAM BOILERS .	(Exclusive of water-gas plant), for driving pumps, exhausters, sulphate plant, etc. Two required—one as a stand-by, including seatings	1,200	4·6	8·0
BUILDINGS . .	(Other than retort and water-gas houses). *Exhauster House.*—(Say) 20,000 cubic feet capacity, at 5*d*.	420	1·6	2·8
	Meter and Governor House.—Do.. .	420	1·6	2·8
	Boiler House.—12,000 cubic feet, at 4*d*., also chimney	300	1·2	2·0
	Generating House, Stokers' Lobbies, etc.—25,000 cubic feet, at 5*d*.. .	520	2·0	3·5
	Steel-framed purifying shed to cover purifiers and preparing floor, 11,500 square feet area, at 1*s*. 6*d*. . .	860	3·3	5·7
TAR AND LIQUOR STORAGE.	One or more wells brick-rendered. Minimum capacity 5 weeks, maximum make of tar and liquor (say) 225,000 gallons, then capacity required 36,000 cubic feet, *i.e.* well 60 feet × 50 feet × 12 feet deep, divided into two or more sections. Average cost per cubic foot = 8*d*. .	1,200	4·6	8·0
PAVING, DRAINING, FENCING & INCIDENTALS	. . . . .	1,300	5·0	8·7
SULPHATE PLANT	(Exclusive of steam boilers), with purifiers for waste gases. Approximate make 475 tons per annum, or (say) 6½ tons per day working 72 days per year	1,200	4·6	8·0
	Building for above plant. 30,000 cubic feet, at 6*d*. per cubic foot .	750	2·9	5·0
	Carried forward	£71,330	274·2	475·8

		£	£ per mouthpiece.	£ per ton of coal per max. day.
	Brought forward	71,330	274·2	475·8
VARIOUS . . .	*i.e.* Tools, carts, weighbridge, and other appurtenances.	1,000	3·8	6·7
	Offices, laboratory, manager's or foreman's house, furniture and equipment. Stores	6,000	23·1	40·0
MAINS (Steam, water and gas connexions)	On works only	3,000	11·5	20·0
	Total expenditure on works (less water-gas apparatus) . . .	£81,330	312·6	542·5
	From the above it is seen that the complete equipment of a works of this size entails an expenditure of over £300 per mouthpiece, and about £540 per ton of coal carbonized per maximum day. This, of course, is exclusive of expenditure on water-gas plant. The cost per 1,000 cubic feet per maximum diem would be £45.			

CARBURETTED WATER-GAS PLANT

	£
Make per day 20 per cent. of total make = 450,000 cubic feet.	
Plant in two sections, each 250,000 cubic feet capacity per diem. Complete with generators, carburettors, superheaters, scrubbers, condensers, and operating floor; also blowers and engines for same, tar well, coke lift, pumps, etc.	4,000
Boilers and seatings for above	950
Exhausters (in duplicate), 25,000 cubic feet per hour, with engines . .	450
Purifiers for oxide of iron only, 20 feet × 20 feet × 5 feet deep, complete with connexions and lifting gear	2,000
Building for water-gas apparatus, 65,000 cubic feet, at 5*d.* to 5½*d.* .	1,450
Shed for purifiers, with preparing floor to cover 6,000 square feet, at 1*s.* 6*d.*	450
Oil-storage tank. Thirty-six days' consumption at 2½ gallons per 1,000 cubic feet of gas made, 45,000 gallons, complete with fittings . . .	350
Carried forward . . .	£9,650

	£
Brought forward . . .	9,650
Meter to pass 25,000 cubic feet per hour	400
Relief holder, 30,000 cubic feet capacity, at £42 per 1,000 cubic feet .	1,260
Gas, tar, steam and water connexions	250
Total cost of complete water-gas plant, *i.e.* £23 per 1,000 cubic feet per max. diem	£11,560
(*N.B.*—For a comparatively small outlay, one section could be increased to 300,000 cubic feet per diem.)	
Cost of coal-gas plant.	81,330
Total cost of works	£92,890

Cost per million cubic feet *made* per annum . . .	£186
* Cost per million cubic feet *sold* per annum . . .	£194
Cost per 1,000 cubic feet *made* per max. diem . .	£41 10*s.*

* Estimated at 480 million cubic feet.

DISTRIBUTION

Without knowing the general outlines of the district and the system of distribution to be adopted, whether high-pressure mains will be run in addition to low-pressure, or whether "boosting" will be necessary, it is difficult to give anything more than an approximate figure under this item. The following, however, may be taken as typical, and generally conforming to the case in question.

		£
MAINS	About 110 miles; these would vary from about 24 inches for trunk mains to 4 inches for the smaller offshoots.	65,000
SERVICES. . . .	To supply 6,500 "ordinary" and 8,500 "slot" consumers, also for industrial purposes . .	17,000
METERS	"Ordinary," 6,500, including fixing, at £2 each.	13,000
	Prepayment installations, 8,500 at £5 each, inclusive of cooker, 3 fittings, piping, etc. .	42,500
COOKERS, FIRES, ETC.	For "ordinary" consumers (including fixing) (say) 3,500	12,500
	Total cost of distribution equipment . . .	£150,000

N.B.—Columns and lamps for public lighting are usually the property of the local authority; but, if rented from the gas company, the cost to the latter would be about £4 10*s.* per lamp complete, including column, lantern, and service. In the above instance from 1,200 to 1,400 would be required, entailing an additional expenditure of about £5,500.

SUMMARY

	£	Percentages of total outlay.
Total cost of works	92,890	34·0
Total cost of distribution	150,000	55·0
Engineering and contingencies, 10 per cent.	24,000	8·8
Law and Parliamentary charges, 2½ per cent.	6,000	2·2
	£272,890	100·0

Capital expended per million cubic feet *made* per annum . . £546
Capital expended per million cubic feet *sold* ,, . . £570
Capital expended per *thousand cubic feet made* per max. day . £120

The foregoing estimate has been set out more or less in detail in order to show the methods employed for arriving at the approximate expenditure entailed in the erection of a comparatively large works. In order, however, that this book may be of assistance in the case of estimating for small works, it has been thought advisable to include figures giving expenditure which may be taken as typical for, first, a 50-million, and secondly, a 15-million concern. The items given are taken from actual figures for works recently erected and now in operation, and the costs are tabulated in such a manner as to show the difference in every item of expenditure.

The figures given for Works "A" concern an undertaking selling 50 million cubic feet per annum in a semi-country district, with small mining and other industries, and a population of from 14,000 to 15,000.

The sale of gas is made up as follows:—

1,500 prepayment consumers at 12,000 cubic feet	18 mills.	per annum.
900 ordinary consumers at 33,000 cubic feet .	30 ,,	,,
Public lighting	2 ,,	,,
	50 millions.	

The figures for Works "B" are for the 15-million undertaking, made up of three small towns in a partly rural and partly residential district. The sales are accounted for as follows:—

500 prepayment consumers at 11,000 cubic feet	5·5 mills.	per annum.
300 ordinary consumers at 32,000 cubic feet .	9·6 ,,	,,
Public lighting	0·5 ,,	,,
	15·6 millions.	

In the latter case it will be noted that the length and cost of mains is excessive, owing to the linking-up of townships by a large proportion of unproductive main. All costs include connexions and foundations complete.

COSTS OF WORKS AND DISTRIBUTING PLANT

	"A" 50 millions.	"B" 15 millions.
	£	£
Land: "A," ¾ acre; "B," 1 acre	500	300
Fencing, paving, and draining	160	100
Retort house and coal store	1,700	720
Retort settings, floorings, chimney, accessories ("B" has very small margin)	2,550	780
Condenser	150	60
Exhausters ("A" in duplicate), also engines	350	120
Coal truckway for feeding store	240	—
Scrubber	355	150
Livesey washer	100	—
Purifiers and oxide shed and traveller complete ("A" of ample size, "B" slightly deficient)	1,110	400
Station meter	380	100
Holder (one in each case)	5,280	2,060
Governor (one in each case)	110	45
Boilers (in duplicate), seating, and chimney	730	—
Tar and liquor storage	370	75
Buildings, stores, etc.	650	340
Small pumps, tanks, tools, etc.	180	100
Works' connexions (small for "A," extensive for "B")	220	170
Weighbridge	65	—
	15,200	5,520
Engineering and contingencies	1,000	130
Total works' costs	£16,200	5,650
Mains: "A," 18 miles; "B," 10 miles	9,800	5,200
Services, ordinary and slot	2,450	830
Meters, ordinary, including fixing	1,750	610
Stoves and fires, ordinary consumers (and fixing)	1,450	400
Prepayment installations, complete, including 3 points, 3-1t. or 5-1t. meter, and cooker or griller	6,750	2,380
	22,200	9,420
Engineering and contingencies	600	90
Total distribution costs	£22,800	9,510

	"A" 50 millions.	"B" 15 millions.
	£	£
Works	16,200	5,650
District	22,800	9,510
Parliamentary and promotion costs	2,000	610
Total capital outlay	£41,000	15,770
Capital cost per million *sold*: Works	324	360
District	470	606
Parliamentary	40	39
Total	£834	£1,005

CHAPTER II

FOUNDATIONS, GASWORKS' BUILDINGS, ETC.

EMPHASIS has already been laid upon the advisability of securing a gasworks' site which is of low-level in comparison with the major portion of the district to be supplied. The works, however, will not necessarily be erected on the lowest-lying portion, as it may give rise to trouble in connexion with water or bad foundations. Certainly, money may usually be saved in the first instance; but unsuitable, spongy subsoils are almost invariably associated with land of this description, and untold damage may afterwards be occasioned by abnormal flooding. Nevertheless, in some cases other attractions may more than balance the prospect of an excessive expenditure on foundations, and gasworks have before now been erected on land reclaimed from the sea. Accordingly, the choice of the site must not be influenced by consideration of the immediate saving, and the various factors require to be carefully balanced before any hasty decision is come to.

Before a site is definitely purchased, trial borings must be sunk, so that a fair indication of the substrata may be obtained. On an extensive site one such boring is by no means sufficient, as comparatively abrupt changes in the character of the strata are frequently found. The more general practice is to sink a circular boring about four feet in diameter, the sides of the excavation being shuttered up by means of a light wooden casing as the digging advances. The casings are usually worked in about 6-feet lengths. A less costly and laborious method consists in driving down a special boring auger, which brings the core to the surface as it proceeds, thus enabling an accurate knowledge of the character of the subsoil to be obtained. An auger, complete with the necessary boring outfit, is shown in Fig. 1. The first step is to sink a shallow pit 3 or 4 feet deep by about 4 feet square, and to shutter this up with timber. The shear-legs is then erected over the centre of the pit, and the boring rope is connected to the end of a special joint rod, to the other end of which the auger itself is attached. The auger is then drilled into the earth by a twisting motion, and periodically withdrawn by means of the windlass for the removal of the strata. The sketch shows a "clay" auger in use. It is found that with normal soils of the clay and soft gravel type a core of strata about 3 feet in length may be brought up at each operation. In the event of the soil proving extremely hard, and of a rocky nature, a special tool of a chisel type is employed, and the strata broken up by a series of blows. Strata drills of this kind may be used for boring shafts of from 4 inches to 2 feet in diameter; for

most purposes the smaller holes will give ample indication of the nature of the ground. The 4-inch boring is, however, not to be advised; and for the majority of sites the 8-inch drill—as stipulated by the London County Council—is certainly to be recommended. Having once bored the hole, observations of the rise and fall of water must be made. These should extend over some period, and may usually be carried out merely by dipping at fairly frequent intervals, particular attention being given to the effect of heavy rainstorms, or other causes likely to influence the water level. Trial boreholes must on all occasions be taken lower than the probable depth of the foundations, so as to remove all doubt as to the character of the proposed bed; whilst strata of a gravelly nature should be regarded with suspicion, in that they may eventually prove to be interspersed with seams of running sand.

Before the excavation proper for foundations is commenced steps must be taken for the adequate control of all surface and sub-surface water; in fact it may in abnormal cases be found profitable to lay down a drainage system which is capable of dealing with water to a depth somewhat below that of the proposed excavations. This procedure is, however, decidedly costly, and should only be countenanced in extreme instances.

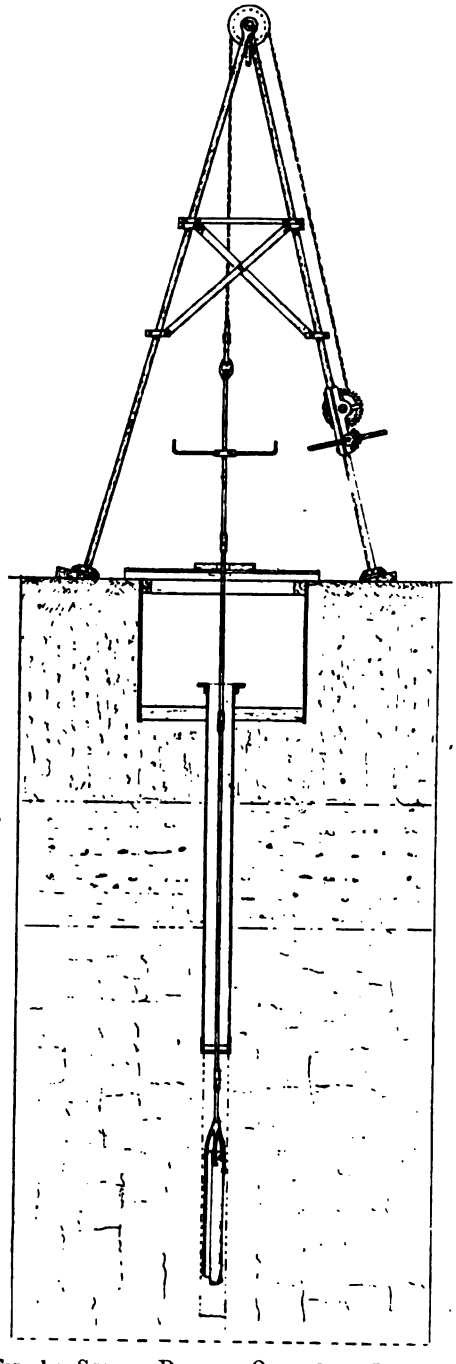

FIG. 1.—STRATA DRILL IN OPERATION, FITTED WITH BORING AUGER TO RECOVER SUBSOIL IN LENGTHS OF 3 FEET 6 INCHES.

FOUNDATIONS

When the depth of an excavation exceeds a few feet, some method of timbering must usually be employed, whilst when the depth is greater than 10 feet, considerable precaution is necessary, so much so that the Board of Trade prescribe that in such cases an expert shall be called in. The excavation of ground for gasholder tanks calls for particular care and experi-

ence. In general, foundations are classed under the two headings of "natural" and "artificial," according as to whether the ground requires special treatment other than shallow excavation. In this country the four most common subsoils to be met with are (*a*) ordinary earthy material, (*b*) hard and soft clay, (*c*) gravel, and (*d*) chalk; and it is the compressible soils of the soft clay and earthy types which demand the greatest amount of attention.

It may be said that as a general rule (particularly where foundations for retort benches are concerned) it will be profitable to put down a solid block of concrete, so long as the total depth does not exceed 5 feet. Beyond this the procedure becomes expensive, and one of the various "artificial" methods should be resorted to. The cost of excavation will, of course, largely depend upon the material which is being taken out; but if a good ganger is in charge, he will often find some means of selling the débris, or of getting it carted away by a local contractor free of charge. When the conditions of the substrata necessitate a comparatively deep foundation, or when the soil is more or less compressible, the following methods may be employed:—

(*a*) Concrete piers.
(*b*) Floating foundation.
(*c*) Piles, either wood, metal, or reinforced concrete.

Particulars of the pier methods are shown in Fig. 2, from which it will be seen that the complete area is first excavated to a depth of a few feet, whilst at intervals shafts are sunk through the soft soil on to the stable ground. The dimensions of these shafts vary with the purpose for which the foundation is required, but they will usually run about 2 feet in width, and extend laterally the entire breadth of the foundation. For buildings, etc., the piers may be so much as from 20 to 25 feet apart, rough arches being thrown from pier to pier by digging out the ground, so as to form a centering. When dealing with retort bench foundations it is usual to drop down a pier beneath each supporting wall of the main setting-arches; hence in such cases the piers are pitched at about 8 to 10 feet centres. When the subsoil necessitates sinking to a greater depth than 12 feet, it is advisable to discard the pier method, and to drive down reinforced concrete piles, which may be employed in the form of continuous piers, or spaced at equal distances apart. In the latter case the stability of the upper slab should be ensured by running some type of reinforcement, such as old railway metals, from head to head of the piles, or by introducing one of the many systems of special bars or metal. In fact, any method may be employed which has the effect of forming a continuous slab by binding the heads of the piles together, thus ensuring equal loading.

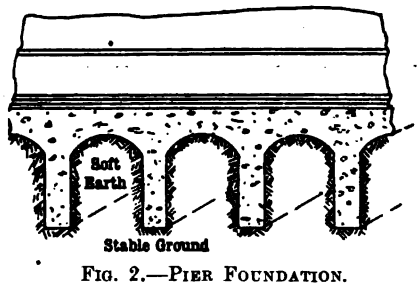

FIG. 2.—PIER FOUNDATION.

To-day, the favourite method of dealing with average compressible soil is by means

of some type of floating foundation in the form of a raft, often with stiffening ribs as in a large ceiling. That is to say, the weight of the superstructure is distributed over a large area, so that the unit loading on the soil is within the recognized limit. In such cases the distribution of loading must be as equal as possible; otherwise, if sinking occurs, the whole may go slightly out of level. In this respect it must be remembered that it is frequently impossible to avoid a little sinking; but unequal sinking is the great danger. The once familiar type of grillage foundation, embracing an elaborate network of joists bolted together, is now giving way to reinforced concrete work, this having proved to be the most economical form of foundation which can be employed under any circumstances. An alternative but more expensive method is that of employing one of the many forms of metal sheet piling, thus completely enclosing the space to be built over. A very light raft spread over the enclosed area will then suffice. This is certainly an admirable way of dealing with soils of a spongy character. As an illustration of its efficacy, it may be mentioned that in America buildings have been erected on what has practically amounted to a body of water, the latter, being incompressible, affording an ideal support so long as lateral movement is effectively restrained.

Some few years ago it was a common practice to set down raft foundations constructed from timbers tied together, also from fascines; but such methods may now be looked upon as things of the past. As an example of the modern slab foundation, an illustration of a method adopted for the erection of a vertical retort bench and house is shown in Fig. 3. Fig. 4 shows such a foundation with the reinforcement in position before the concrete is inserted. Here the slab is of a more or less shallow nature, but is heavily reinforced by means of indented bars. The disposition of the bars is such that they are called upon to relieve the concrete of the greater part of the tensional and shear stresses. In the case shown the foundation was required to support several rows of columns, each carrying a load of approximately 90 tons; accordingly the maximum reinforcement occurred in open squares in alignment with the columns, whilst the remaining portions of the slab were provided with considerably less reinforcement. When foundations of the floating type are employed on the more easily compressible soils care is necessary to see that no derangement takes place, otherwise adjacent buildings may suffer disturbance. Foundations, to-day, however, are not of the massive character employed in the past, owing to the tendency to erect light steel-framed buildings with a comparatively thin filling.

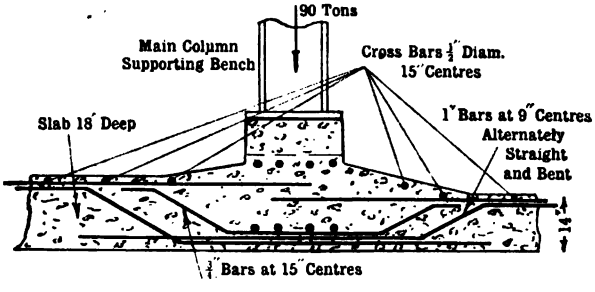
90 Tons
Main Column Supporting Bench
Cross Bars ½" Diam. 15" Centres
Slab 18" Deep
1" Bars at 9" Centres Alternately Straight and Bent
14"
½" Bars at 15" Centres

FIG. 3.—TYPICAL REINFORCED RAFT FOUNDATION FOR VERTICAL RETORT BENCH.

FIG. 4.—REINFORCED RAFT FOUNDATION FOR VERTICAL RETORT BENCH, SHOWING INDENTED BARS IN POSITION BEFORE CONCRETING-UP.

ALLOWABLE PRESSURES ON VARIOUS SOILS

Gravel (firm) with underlying chalk	6 to 7 tons per square foot.
Firm gravel	5 „ 6 „ „ „ „
Firm clay	3 „ 4 „ „ „ „
Gravel (loose) and sand	1½ „ 2½ „ „ „ „
Light earth and sandy loam	¾ „ 1¼ „ „ „ „
Made-up ground (well rammed)	½ „ ¾ „ „ „ „

When slabs of concrete for retort benches are laid down on any type of clay it will be found profitable to drop a layer of fine sand (from 3 inches to 6 inches deep) on to the surface of the clay before filling in with concrete. Concrete, being of a homogeneous nature, readily conducts heat, so that in time the moisture is dried up from the clay, with the result that shrinkage occurs, and the whole may be thrown out of level. The strength of the concrete is a question to which due thought must be given, and this particularly applies to gasworks undertaking extensions, where there is usually a stock of " hard-core " on hand. The gas engineer is very prone to get rid of his old broken retorts on such occasions, and in many instances there is little reason why these should not be used in moderation. It must be remembered, however, that the modern highly porous retort has a low crushing strength, and in view of this fact it is best excluded from the more important work. Cement concrete is nearly always used nowadays in preference to the lime variety, owing to its greater strength, and should seldom be mixed in higher ratios than 1 to 6, unless the ground is good, in which case a mixture of 1 to 8 or 9 may be safely used. The aggregate is best composed of a fairly coarse ballast, or hard bricks broken to a size not exceeding 2 inches, with an adequate proportion of sand. Care must be taken to see that all mortar adhering to the bricks is removed. Concrete mixers are a present-day fashion, but except for extensive building opera-

tions in reinforced work it is questionable whether they effect any marked economy. Many authorities are of the opinion that the hand-mixed material is far superior.

It is difficult to lay down any hard and fast rule for the cost of foundations, but in the case of the ordinary rectangular slab an average figure would be 13*s.* 6*d.* to 16*s.* 6*d.* per cubic yard complete, including excavation to a depth not exceeding 4 feet.

Excavation only varies from 10*d.* to 1*s.* 6*d.* per cubic yard up to a depth of 4 feet; beyond this depth it will be from 1*s.* 6*d.* to 2*s.* 6*d.*, which includes light timbering.

MODERN GASWORKS BUILDINGS

Engineers in the past have not neglected to add an artistic touch to the architecture of the gasworks, and evidence of this is seen in the cast-iron embellish-

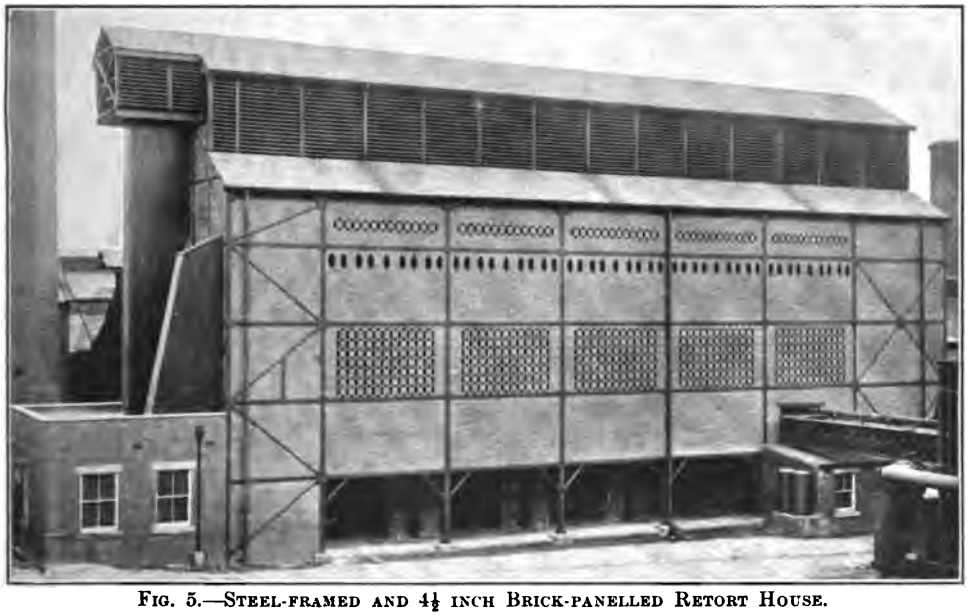

FIG. 5.—STEEL-FRAMED AND 4½ INCH BRICK-PANELLED RETORT HOUSE.

ments, finials, etc., introduced for the supposed beautification of certain plant and buildings. It would appear, however, that the tendency of the present age is in the direction of utility alone, it being realized that under no circumstances can a gasworks be represented as ornamental; hence simplicity of design has commenced to assert itself at every turn. So far as the general style of buildings is concerned, economy goes hand-in-hand with simplicity of outline; accordingly these two must rank as primary considerations. Other factors bearing on the ultimate decision are:—

(*a*) Wear and tear, the cost of maintenance, re-painting, etc.

(*b*) The choice of materials suited to the purpose for which the building is

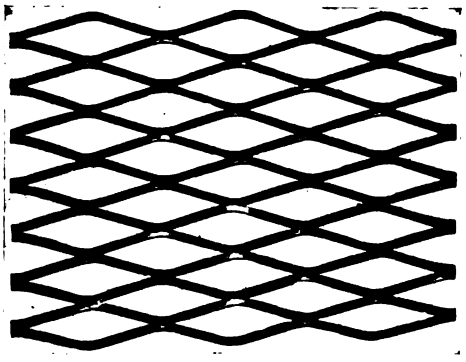

FIG. 6.—EXPANDED METAL.

required, *e.g.* in corrosive atmospheres material such as corrugated iron should be dispensed with.

(*c*) Adaptability for future extensions without the necessity for considerable destruction.

(*d*) Ample provision for the reception and dispatch of materials in connection with the operation for which the building is required. In the case of engine houses, large entrance doors should be provided, so that the instalment of larger plant in the future will not necessitate cutting through walls.

(*e*) The buildings should be roomy, and of ample height, with efficient means for ensuring ventilation.

(*f*) There must be an abundance of light.

(*g*) The prevailing conditions should be easy and congenial for the men, facilities being afforded for keeping themselves and their apparatus in a state of cleanliness.

FIG. 7.—WATER-GAS HOUSE IN STEEL FRAMEWORK, EXPANDED METAL, AND CONCRETE PLASTERING. SOLID WALLS 3 INCHES THICK.

In the past it has been an almost universal custom to erect such buildings as retort houses of substantial dimensions in brickwork, although later the steel-framed structure entirely sheeted with corrugated iron found a certain amount of favour in small works. Both methods, however, have their disadvantages. The first is excellent once it is erected, but the capital expenditure is excessive, being as much as 4*d.* per cubic foot, inclusive of roof and foundations. Corrugated ironwork,

FIG. 8.—HY-RIB METAL.

on the other hand, is economical when considered in the light of first cost, but is a never-ending expense so far as maintenance and painting is concerned. In any case, if a corrugated structure is decided upon, it should be understood that in no circumstances should the sheets be brought down to ground level. A dwarf concrete wall, about a foot to 18 inches in height, should be provided, the sheets

FIG. 9.—INTERIOR VIEW OF HY-RIB WALL AFTER ONE COAT OF PLASTER ON OUTSIDE.

being brought down to the top of this. During recent years there has been a growing tendency to dispense with both corrugated iron and massive brickwork, and the light steel-framed house panelled with thin brickwork is making considerable headway in this country. An illustration of this type of building, which can be effectively used for retort house, engine house, and all classes of buildings, is shown

in Fig. 5, where the brickwork is 4½ inches thick. The approximate cost, including foundations and roofing, is 2½*d.* to 3*d.* per cubic foot of content.

Another very cheap method of construction is that which introduces patent metal meshings, such as expanded metal or "Hy-rib." Retort houses and other buildings built up with the aid of such material are primarily provided with a steel frame, as in the case of the brick-panelled house, but the open squares between the main framing are filled in with the metal meshing, and the whole is then given a plaster coating. Examples of expanded metal-work are given in Figs. 6 and 7, whilst the "Hy-rib" is seen in Figs. 8, 9 and 10. The plaster is usually composed of 3 parts of Portland cement to 11 or 12 parts of sand, and the total thickness of the side walls varies from 1¾ inches to 3 inches, in accordance with the spacing of the supports. The approximate cost of a building on the "Hy-rib" principle amounts to an average of 2*d.* to 2¾*d.* per cubic foot of contents, which includes foundations, sashes, glazing, doors, or roller shutters.

Fig. 10.—A Vertical Retort House in Hy-Rib and Concrete Filling.

For vertical retort houses this type of structure has proved particularly suitable, this being largely due to the fact that the vertical house may be built far more lightly than that for horizontal retorts, owing to there being no heavy floors to support; but it is not to be recommended for buildings having an excessive number of sashes, openings, etc., as the extra cost of providing framing for these is appreciable.

Comparative Costs of Various Buildings

Massive brickwork, old type, slated roof	3½*d.*	to	4*d.*	per	cubic	foot	contents.
Entire brickwork (modern), slated roof	2¼*d.*	„	3¼*d.*	„	„	„	„
Steel frame, corrugated sheeting throughout	2*d.*	„	2½*d.*	„	„	„	„
Steel frame, brick panelling, slated roof	2¼*d.*	„	3*d.*	„	„	„	„
Steel frame, trussed patent metal and plastered, slated roof	2*d.*	„	2¾*d.*	„	„	„	„

(All complete with foundations.)

In the case of the last-mentioned item, the expenditure would be made up approximately as follows :—

Foundations	0·70*d.*
Building	1·50*d.*
Roofing	0·55*d.*
	2·75*d.* per cubic foot.

With the concrete structure much depends, of course, on the comparative cost of bricks and ballast on the site. If the latter can be dug from the subsoil the concrete building is inapproachable on grounds of economy. In one instance a building of this type was recently erected for rather less than 1¾*d.* per cubic foot. The total capacity amounted to 750,000 cubic feet, the foundations were 6 to 8 feet deep, and the concrete forming the sides was shuttered up to a height of 24 feet, the remaining 10 feet to the eaves being composed of moulded concrete blocks. In this case ballast was obtainable from the site, and the major part of the foundations were composed of 3 parts of coke breeze, 3 parts of clinker, 3 parts of washed ballast, and 1 part of cement. The filling material and concrete blocks were made up of 7 to 8 to 1 concrete, 3 parts of this being ballast. In structures of this type care should be taken to ensure that clinker or breeze in the concrete does not come into actual contact with the steelwork.

So far as retort-house construction is concerned, a usual rough rule for arriving at an approximate cost for a brick-panelled or brick and concrete house per mouthpiece to be installed is the following :—

For stage house	£24 to £18 per mouthpiece.
For subway house	£22 „ £12 „ „

These prices include merely the house and coal store, and no machinery, retort-bench work or flooring. They allow, however, for foundations. The lower margin given applies to the larger houses of (say) more than 150 mouthpieces. For a medium-sized stage house take £26 to £35 per mouthpiece.

THE DESIGN OF COAL STORES

Although the brick-panelled or plastered-steel structure admirably serves the purpose of affording a covering to the retort-bench, the whole question requires somewhat serious consideration when the storage of coal is concerned. Thin plaster, or 4½ inch brickwork walls are in no sense capable of withstanding for long the lateral thrusts of a deep coal heap, and although cases are known where such buildings are being used for the purpose without visible detriment, there is little doubt that the factor of safety is extremely low, and considerable risks must be run. For all this, there is no reason why the light concrete house should not be employed for storage purposes, so long as those portions acting as retaining walls are effectively reinforced on the inner or tension side. A good plan is to employ old railway metals, these being rigidly interlaced with piping or iron rods of about ½-inch to 1-inch diameter. In the light panelled buildings the steel framing must be closer

and stronger, whilst a thin wall can be made of many of the patent reinforcements on the market.

If large coal-stocks are to be regularly maintained under cover it cannot be disputed that the entire brick building, panelled and buttressed, provides the best form of shelter. Formerly these structures were erected almost without exception, and the fact that they are still doing duty as both coal stores and houses to-day speaks well for their design and durability; and the same may be said of thick concrete or stone walls. If perfect reliance is to be felt, it is essential that the walls of coal stores should be designed on scientific lines, and the pressures due to the coal carefully computed. For this purpose the well-known Rankine formula for earth pressures may be employed, and the wall will be sufficiently stable if the middle-third condition is neglected, and the resultant pressure cuts the various sections within the width of the base at any one section. In working out the pressure the weight of ordinary bituminous coal may be taken as 54 lb. per cubic foot, and the angle of repose as 45°. Then the formula is:—

$$P = \frac{Wh^2}{2}\left(\frac{1 - \text{Sin } \varphi}{1 + \text{Sin } \varphi}\right)$$

Where P = total pressure per foot run at a depth of h feet.
W = weight of coal per cubic foot = 54 lb.
φ = the angle of repose of coal = 45°.

For instance, suppose it is required to find the thickness of walls necessary for stacking coal to a depth of 15 feet. Then—

$$P = \frac{54}{2} \times 225\left(\frac{1 - \text{Sin } 45}{1 + \text{Sin } 45}\right). \left(\text{Sin } 45° = \frac{1}{\sqrt{2}}\right)$$

From this, P is found to be 1,042 lb. at a depth of 15 feet, or an average pressure of 69 lb. per square foot. This gives the total horizontal pressure at the bottom of the wall, and from the triangle of forces the position of the resultant may be found, and, accordingly, the thickness of the wall at the base. If the same treatment is applied to find the pressure at various depths, the allowable decrease in thickness as the wall rises is obtained.

In cases where the wall simply serves as a retaining wall, so that coal can be surcharged above it, the formula must be used in the following somewhat complicated form, viz.:—

$$P = \frac{Wh^2}{2} \cdot \text{Cos } \gamma \left(\frac{\text{Cos } \gamma - \sqrt{\text{Cos}^2 \gamma - \text{Cos}^2 \varphi}}{\text{Cos } \gamma + \sqrt{\text{Cos}^2 \gamma - \text{Cos}^2 \varphi}}\right)$$

where γ is the angle of surcharge.

This, however, reduces itself to a simple and easily workable form when the angle of surcharge is equal to the angle of repose of the coal, as would nearly always be the case. The formula then becomes:—

$$P = \frac{Wh^2}{2} \cdot \text{Cos } \phi$$

The above treatment, of course, applies to the stacking of broken or small coal. When the coal itself is formed into a wall (as commonly seen in railway yards), a reduced wall-thickness may be taken.

When the erection of coal stores is contemplated, the question of chief importance is as to whether the projected floor-level is of sufficient height to escape ground water after a heavy rainfall, also its relation to the level of the retort-house working stage. The floor should preferably be paved with slabs of stone or concrete, and designed so that moisture can drain away. In this respect the design in Fig. 12 is to be preferred to that shown in Fig. 11. The practice is often followed of dividing

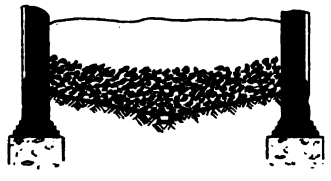

FIG. 11.

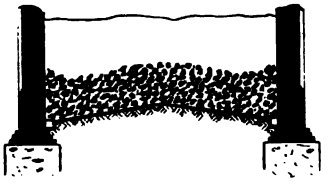

FIG. 12.

the store into separate bins by means of vertical cross-walls, and this is certainly of advantage in preventing a fire from spreading. Moreover, each of these bins can be made of a definite capacity (so many tons per foot deep), which enables a good idea of the stock to be obtained at a glance. Iron columns and ties passing through bins should be avoided as far as possible, as they are said to favour the spread of fire—in any case they should be coated with concrete. Plenty of fresh air in the covered store is an important item, for men suffer from the ill-effects of a poorly ventilated building. This is supposed to be due to the vapours of acetaldehyde, which are known to interfere with respiration. Ventilation is best provided for by a continuous louvre running along the roof of the store, or by large openings made above the level at which it is proposed to stack coal.

TYPES OF RETORT HOUSES

There are two standard types of retort houses to be found in use at the present day, whilst a third but less common structure is also met with at some works. These are :—

(*a*) Stage houses.
(*b*) Subway houses.
(*c*) Intermediate type. A combination of (*a*) and (*b*).

Included under (*a*) are all those houses in which the clinkering-floor is on the ground-level, whilst the charging-floor is elevated. The modern vertical retort house, although differing from the horizontal type in many respects, would also come under this heading. The former houses are invariably of greater height than the latter, averaging (for the 25-foot retorts) about 52 feet to the eaves, whilst horizontal houses are seldom more than 40 feet. " Vertical " houses, moreover, can be made of fairly light design, as—unlike the house for " horizontals "—they have

only to support themselves, and to withstand the wind pressure to which they may be subjected. In the subway house the charging-floor is on a level with the mean ground-level, the ground being excavated so that producers, slides, etc., are all below. The intermediate type is seldom met with, and includes all those houses which have the charging-floor partly above ground-level and the clinkering-floor below it. The existence of a subway house may in many instances be accounted for by the fact that a works originally started in a more or less small way with direct fired settings —in which case a single floor is sufficient, this being at ground-level. As business increased it may have been decided to adopt some more efficient type of firing, which, owing to the increased room required in order to ensure a deeper fuel bed, means either raising the roof or excavating, the latter course very frequently being preferred. Before making a decision, however, great care is necessary to see that the surface of the proposed foundation will not be below the high-water level. In any case it is preferable to enclose the whole of the subway with an impervious sheeting. This may be done by lining the sides with concrete, backed with puddle, or with rendered brickwork; but preferably by building twin walls and filling in the intervening space with pitch.

In spite of the increased expenditure entailed with the stage house, it is almost without exception the favourite for modern retort-house work. The conditions under which men are called upon to do their work receive far greater attention than in the past, and it is generally recognized that the intense heat of the majority of subways, with the escaping steam arising from quenched coke or clinker, and the inability to adequately ventilate the subways, is anything but conducive to the honest performance of duty. On the other hand, the stage house can be effectively ventilated, coke quenching is facilitated, and steam can be quickly got rid of. The coke, moreover, can be wheeled out direct into carts, this also applying to ashes and clinker. In the case of the subway house, some means has to be provided for bringing the ashes (and in many cases the whole of the coke) to ground-level.

So far as the intake of coal is concerned, the subway house will in some instances hold the advantage, in that the coal when deposited in the store is at charging-level. With the medium and larger sized houses this cannot, however, be said to be of great importance, owing to the common use of some form of coal-handling plant. With small houses, where hand-charging is in vogue, the point is of some importance.

The distance between the upper and lower floor-levels varies from 5 to 10 feet, the former being the allowance in very small subway houses; but if adequate depth is to be given to the producer, the height should not be less than 8 feet. As regards this, it will be seen from Fig. 13 that in the stage house the difference between the floor-levels accounts for a certain bulk of coal which has to be brought to the working tage. This increases the cost of handling, unless the store is fitted with elevators for feeding overhead hoppers. This is not the case with the arrangement shown in Fig. 14.

A point which has accounted for a good deal of discussion is the effect of the type of house on the air supply to the producers. Some authorities have objection to the stage type owing to its tendency to set up draughts that may influence the

composition of the furnace gases. On the other hand, it is said that a freer air supply is obtained, therefore more regular working of the producers.

As a general rule, however, it will be found that water is the deciding factor,

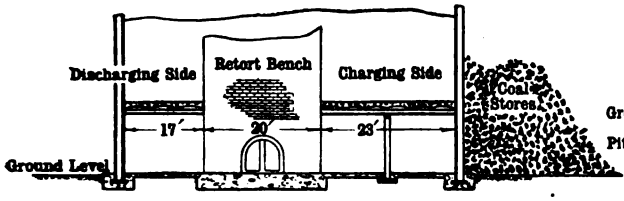

FIG. 13.—STAGE HOUSE.

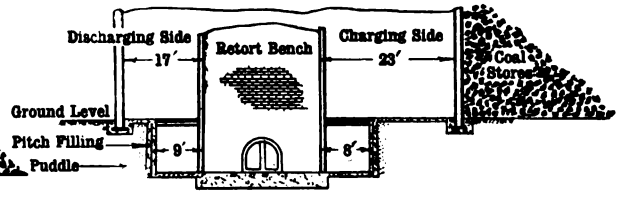

FIG. 14.—SUBWAY HOUSE.

and if this is found near the surface, a stage house should forthwith be decided upon.

Concerning relative costs, it may be taken that the stage house costs anything from £2 to £6 more per mouthpiece than the subway type costs.

In smaller works the subway may be left entirely uncovered, and the retorts

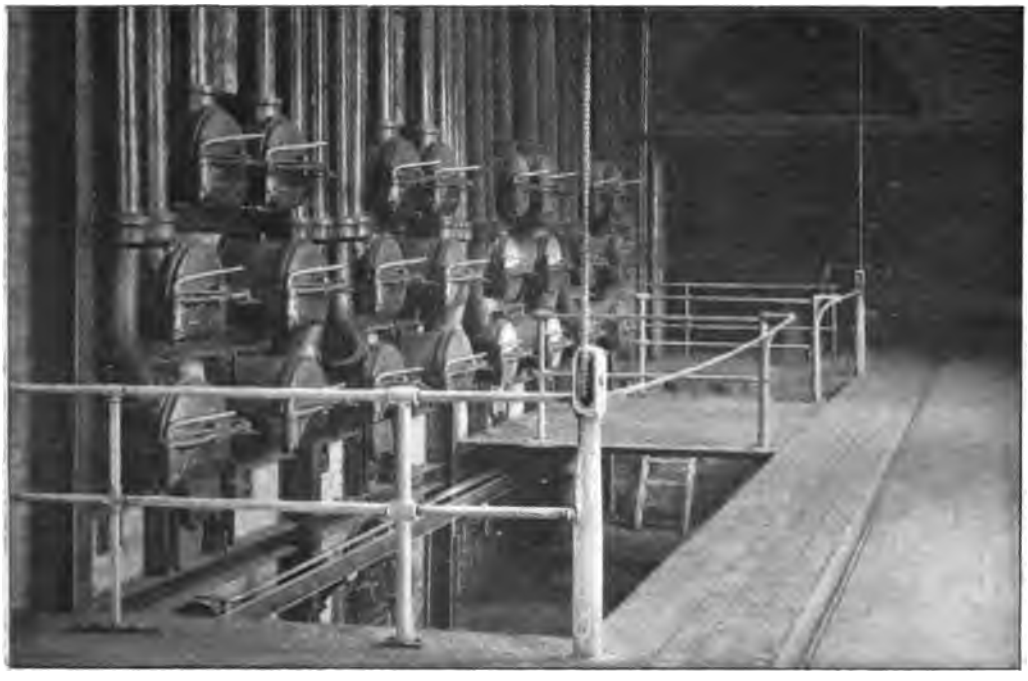

FIG. 15.—TRAVELLING FLOOR FOR SUBWAY RETORT HOUSE.

operated from a travelling platform running on ball-bearings, and readily operated by hand. In such cases the precaution must be taken of railing off the subway, unless this is provided for by a running cable as shown in Fig. 15.

RETORT-HOUSE ROOFS

The use of timber for the construction of principals must be avoided in retort houses. The building for horizontal benches is usually provided with an all-steel truss; the well-known "English" or "French" types made up of all-rolled sections are effective and economical. Slates are the most general covering, although many forms of patent compressed asbestos sheets and tiles, costing about 25 per cent. less than slates, have recently been introduced with success. Owing to somewhat heavy deterioration due to corrosion, steel used in retort-house roofs and other work should not be highly stressed, and a factor of safety of 7 on the breaking strength should be allowed for, *i.e.* a stress not exceeding 4½ tons per square inch in tension or compression.

RETORT-HOUSE FLOORS

Except in connexion with the smaller works the stage house will usually be decided upon, as the many contingent advantages will be found to neutralize the additional first cost entailed. For small works, where any stoking apparatus is in use (such as the manual type), the floor, whether at ground-level or above it, is frequently composed of ⅜-inch or ½-inch chequer plates, bolted down to cross joists. For the larger works, where heavy machines giv ng rise to high rolling loads have

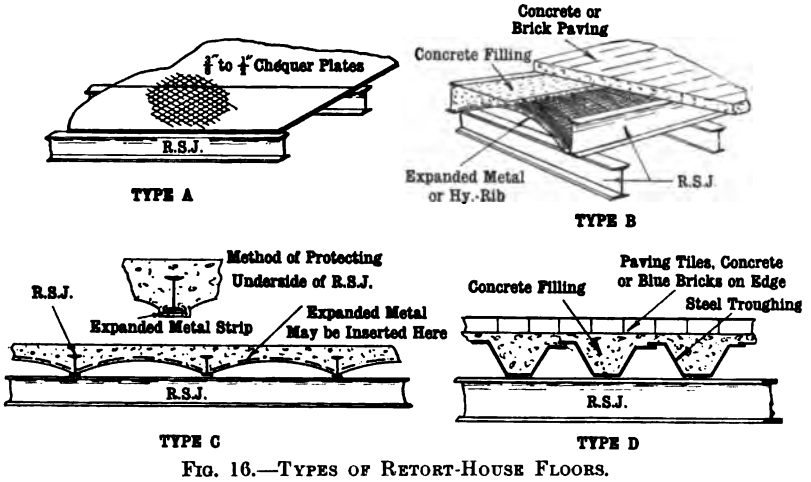

FIG. 16.—TYPES OF RETORT-HOUSE FLOORS.

to be allowed for, additional strength is necessary, and wear and tear on a chequer-plate floor is considerable. Several types of retort-house floors are shown in Fig. 16, and within recent years a tendency has developed to employ some system of reinforced concrete as shown. A serviceable method of building the concrete arches is that of fixing in sheets of thin metal or corrugated iron, these being left in after the work is finished.

A point requiring attention is that of allowing ample room for expansion of the joists composing the floor; otherwise, when expansion of the bench and joists

sets in serious stressing may result in the ultimate yielding of some portion of the structure. It is certainly preferable to arrange for independent columns some inches from the buck-stays, the main floor girders being carried on these, so that the whole floor is completely independent of the bench.

Owing to the continued quenching of coke, the clinkering of fires, etc., the under portion of the steelwork where exposed is particularly liable to corrosion. An effective method of preventing this is to cover the lower webs of the joists with cement, which may be made to cling permanently by attaching a strip of expanded metal as shown in type C, Fig. 16.

The variation in size of retort-house floors makes it difficult to lay down more than approximate figures for their cost. In the main, however, the following may be looked upon as average examples:—

Stage floor.	Chequer plates on single joists .	2*s.* 3*d.* to 2*s.* 6*d.*	per square foot.
„ „	Double joists, concrete arches .	3*s.* 3*d.* „ 4*s.*	„ „ „
„ „	Single joist, trough and concrete .	3*s.* 9*d.* „ 4*s.* 6*d.*	„ „ „
„ „	For charging side, heavy machine .	4*s.* 6*d.* „ 5*s.* 3*d.*	„ „ „

As the wear upon gasworks' floors is somewhat considerable, it is advisable to avoid breeze and clinker in the concrete used for the floors. Where there is a thickness greater than 3½ inches, the best material will be made from 4 parts of aggregate, 2 parts of sand, and 1 part of Portland cement. If the stresses on the floor are computed, the concrete should be neglected and merely regarded as filling, whilst in the case of large retort-house floors the machine loaded to its maximum should be dealt with as a rolling load. The weight, furthermore, must be assumed to act on three wheels only, this often being the temporary condition of affairs, due to a faulty rail, or to some external influence. The centre columns (*see* Fig. 13) usually associated with these heavy floors must be strong enough to take the rolling load and any eccentricity of loading which may be caused by the above-mentioned factors.

CHAPTER III

THE HORIZONTAL RETORT BENCH

THE practice of laying retorts horizontally is still the most common in this country. In spite of the perfection to which other types of carbonizing plant has been brought, the older method is as yet able to hold its own, and there is little fear that it will be universally supplanted. So far as the smaller works are concerned, the horizontal bench is more convenient, and less costly in the first place; and, up to the present, vertical installations have been chiefly confined to those works where comparatively large quantities of coal can be handled with a considerable saving in working expenses.

There are three types of horizontal settings in common use to-day. These are:

1. Direct-fired settings.
2. Semi-gaseous settings.
3. Gaseous-fired settings.

Types 2 and 3, which are gradually taking the place of the more extravagant direct-fired settings, may again be subdivided as follows:—

(*a*) Generator settings.
(*b*) Regenerator settings.
(*c*) Outside producers of various types.

Although the initial cost of the gaseous-fired setting is greater than that of the direct-fired setting, the additional outlay is soon redeemed by the saving effected in fuel. For this reason even small works are finding it profitable to instal at least the generator principle, and it may be said in general that the direct system should be confined to those works making less than 2 or 3 million cubic feet per annum. In such cases, interest on additional capital and extra labour entailed in supervision make the gaseous system a doubtful advantage. In the "direct" furnace the air passes through the coke in large and often unrestricted quantities, and combines with the carbon to form CO_2 directly. In the gaseous settings the retorts are heated by the exothermic reaction of the combination of CO and oxygen in forming CO_2. The great drawback to the direct furnace is the difficulty of controlling the air supply, which results in a considerably increased consumption of fuel, together with irregular heating of the setting. In fact, in very small works, where the plant is not making gas throughout the whole twenty-four hours, cases have been known where all the coke has been made use of for heating the retorts, and in isolated

instances an additional quantity of fuel has had to be purchased from outside. About double the quantity of air enters the furnace than is theoretically necessary, which has the effect of retarding combustion and reducing the limit of temperature. This is chiefly due to the large volumes of nitrogen introduced with the air, and the defect has been overcome in some measure by employing the semi-gaseous system.

The quantity of fuel necessary for the carbonization of coal has, by the curtailment of thermal losses in every direction, been reduced to such fine limits that at the present day, under ideal conditions, the coke required is only about 11 per cent. of the original weight of coal. The fuel consumed under the various systems is normally as follows :—

Direct-fired furnace	40 per cent. of coke made used as fuel.
Generator furnace	22 to 26 „ „ „ „
Regenerator furnace	16 „ 20 „ „ „ „
Vertical retorts—	
(*a*) Intermittent type	23 „ „ „ „
(*b*) Continuous type	16½ „ 18½ „ „ „ „
Outside producers	18½ „ 23 „ „ „ „

In giving figures such as the above the basis of coke made per ton of coal carbonized on which the figures have been calculated must always be stated. In the present instance the yield has been taken as 14 cwts. per ton. It is owing to the widely varying yields of coke from coals that this method of gauging fuel results is somewhat unsatisfactory, and the most reliable basis is that of " lbs. of fuel used per 100 lb. of coal carbonized," such as given in the table below. Chief importance, however, attaches to the coke *actually sold* per ton of coal, and so long as this amounts to 10 cwts. the economy of the system of firing is above question.

Direct-fired furnace	28 per cent. of original weight of coal carbonized used as fuel.
Generator furnace	15 to 18 „ „ „ „ „
Regenerator furnace	11 „ 14 „ „ „ „ „
Vertical retorts—	
(*a*) Intermittent type	16 „ „ „ „ „
(*b*) Continuous type	11½ „ „ „ „ „
Outside producers	13 „ 16 „ „ „ „ „

The low fuel figures for the continuous vertical system are chiefly accounted for by the fact that the heat is extracted from the coke before it leaves the retort, and is utilized for heating up either the primary or secondary air before combustion. It must be pointed out, however, that fuel figures for verticals are at present more or less in the nature of experiments, as there has as yet been little opportunity of making comparisons over prolonged periods.

THEORY OF COMBUSTION

An elementary scientific fact which must be realized at the outset is that a definite amount of coke, whether burnt at once to CO_2 in the direct fire, or in two

stages, as in the gaseous furnace, in each instance yields a similar number of heat units. This may be simply illustrated as follows:—

(1) 1 lb. of carbon burnt direct to CO_2 evolves . . . 14,550 B.Th.U.
(2) 1 lb. of carbon burnt to CO evolves . . . . 4,350 „
1 lb. of CO burnt to CO_2 evolves . . . . . 4,371 „

1st stage. 1 lb. of carbon—

$$C + \tfrac{1}{2}(O_2) = CO$$

1 lb. C = 2·33⅓ lb. CO = 4,350 B.Th.U.

2nd stage. . 2·33⅓ lb. CO = 2·33⅓ × 4,371 = 10,200 „

Total 14,550 „

From the above it will be seen that the greater efficiency of the gaseous principle is not due to the fact that an increased number of heat units are expelled; the reason is that the heat is obtained in that portion of the setting where it is most useful, and the bulk of gases resulting from total combustion is reduced to the smallest practicable limits. It is not proposed to deal here with the calculation of combustion temperatures, as the procedure is explained in most textbooks on physics, and is of little practical use to the gas engineer.

The ultimate limiting temperature is influenced—

(*a*) By the calorific power of the fuel.

(*b*) By the total weight of the products of combustion and their specific heat.

(*c*) By the temperature of the mixture before combustion.

Of these, the first is under control to only a limited extent, as the fuel used—coke—has to be taken as it comes, the calorific power depending upon the type of coal carbonized at the time. It is largely by working on conditions (*b*) and (*c*) that the increased firing efficiency of the present day has been obtained. With regard to the total weight of the products, it will be seen that the greater the quantity of air admitted to the furnace for the combustion of a definite amount of fuel the greater will be the weight of the waste products over which a fixed number of heat units will be spread. Hence, the ideal condition is that of admitting just sufficient air for combustion, and reducing the weights of the waste products to a minimum—in which case the heat units are concentrated in the smallest possible volume and a maximum temperature is obtained.

When pure carbon is completely burnt with no more or less than the requisite quantity of air, a temperature of 3,700° Fahr. is theoretically obtainable; but if the air is in excess to the extent of 25 per cent., the temperature is forthwith reduced to 3,540° Fahr. In the same way, if air is deficient, so that CO alone is formed, then the temperature attained will be only 2,330° Fahr. If pure carbon is burnt in pure oxygen, the resulting temperature is approximately 12,000° Fahr. The effect of the total weight of products on the ultimate temperature is best seen from the following:—

1 lb. of carbon burnt in pure oxygen requires 2·67 lb. of O_2, and gives 3·67 lb. of waste products.

1 lb. of carbon burnt in air requires 11·61 lb. of air, and gives 12·61 lb. of waste products.

The increased weight in the second instance accounts, in the main, for a temperature reduction of 8,300° Fahr.

It will be as well to explain here the meaning of the term "Calorific Intensity," which must on no account be confused with calorific power, from which it differs. Calorific intensity is measured in degrees Fahrenheit or Centigrade, and is the maximum temperature theoretically attainable under the conditions of combustion prevailing; hence it depends very largely upon the way in which the fuel is employed.

Producer gas resulting from the combustion of coke should theoretically consist of 34·8 per cent. of carbon monoxide and 65·2 per cent. of nitrogen, by volume. In practice, however, ideal conditions are not to be looked for, and the ordinary individual retort-bench producer is considered to be giving satisfactory results when the carbon monoxide content of the gas averages 25 per cent., the carbon dioxide amounting to about 5 per cent. The modern combustion chamber temperature rarely, if ever, exceeds 2,800° Fahr., and under normal working conditions is usually found in the neighbourhood of 2,500° Fahr., with an actual retort temperature of 1,900° to 2,000° Fahr. Several causes account for the reduced intensity, among them being the variations in the depth of fuel bed, the effect of clinker on the velocity of travel of the gases, and the various sources of thermal losses.

The actual temperature of the fire is of some importance; and whilst the recognized gasworks rule is that of keeping the fuel-bed cool, this axiom can be carried too far, for the maximum proportion of carbon monoxide is reached at a fuel-bed temperature of about 1,400°–1,500° Fahr. The prevailing temperature is from 1,800°–1,900° Fahr.

Producer gas from retort furnaces seldom consists of merely CO, CO_2, and nitrogen; for, owing to steam from the ashpan, also to the impossibility of ensuring the entire "burning-off" of all coke charged from the retort into the furnace, a certain quantity of hydrogen and methane is invariably present. The following, in fact, is the average composition under good conditions:—

Carbon monoxide	25	per cent.	by volume.
Carbon dioxide	5	„	„
Hydrogen	6	„	„
Methane	1	„	„
Nitrogen	63	„	„

With regard to the regulation of the weight of the combustion products, the gas engineer keeps the weight to a minimum by manipulation of the furnace dampers in conjunction with analyses of the waste gases. In order to allow for variation in the composition of the producer gas no attempt is made to admit the *exact* quantity of air required; but the waste of fuel is curtailed by ensuring a slight excess of air—in other words, by admitting sufficient air until oxygen is present in the waste flue gases. The absence of oxygen in these gases is a fairly sure indication of the presence of carbon monoxide—the latter being a useful combustible product, and accounting for the blue flame so frequently to be seen emerging from the chimney shafts of improperly worked settings. An analysis of the gas drawn from the waste flues of a retort setting should approximate very closely to—

Carbon dioxide	19·0	per cent.	
Oxygen	0·4	„	
Nitrogen	80·6	„	

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If oxygen is absent, then CO will be present, and the secondary air should be increased until the required conditions are obtained. At the same time, the above percentage of oxygen is quite within the limits of practical adjustment, and any excess should be curtailed by a reduction of the secondary air supply.

THE EFFECT OF REGENERATION

It has been pointed out that the ultimate combustion temperature is governed in part by the temperature of the mixture before ignition takes place. This being the case, the quantity of heat in the gases before combustion can be added to the heat of combustion; thus the total quantity of heat available for raising the temperature of the waste products is increased in proportion to the intensity of the preliminary heating. Before the introduction of the regenerator, one of the chief causes of loss arose from the escape of the waste products from the retort settings at unnecessarily high temperatures, this occurring in both "direct-fired" and generator settings. In the latter type the secondary air is certainly heated up, but merely at the expense of the producer; and the system owes its greater efficiency mainly to the reduction of losses by radiation, to its flexibility, and to increased facilities for the regulation of the air supply. In such cases the normal temperature at which the gases are allowed to leave the setting is in the neighbourhood of 1,800° Fahr.; but by the transference of sensible heat from these gases to the inflowing secondary air the temperature of the gases has, in the modern regenerator, been reduced by 600° to 800° Fahr. before their escape is permitted, this accounting for a saving in fuel of from 6 to 11 per cent. compared with the generator setting. In the ordinary way the secondary air approaches a temperature of 1,800° Fahr. before combustion.

THE EFFECT OF STEAM

It is unnecessary to enter here into an explanation of the now generally accepted theory of reactions taking place in the fuel-bed during the formation of producer gas. Stated in brief, it is supposed that the main constituents (other than nitrogen) of true producer gas are formed in accordance with the following equations:—

$$(a)\ C + O_2 = CO_2$$
$$(b)\ 2C + O_2 = 2CO$$
$$(c)\ CO_2 + C = 2CO$$

The oxygen entering the base of the bed combines with carbon according to (*a*) and (*b*), with reaction (*a*) predominating and the formation of CO_2 in considerable excess. The CO_2 in travelling through the remainder of the fuel then undergoes reduction in part to carbon monoxide as in (*c*). By far the most important distinction between the reactions, however, lies in the fact that whilst (*a*) and (*b*) are exothermic and disperse heat, (*c*) is endothermic and absorbs heat. In view of this fact, the necessity for avoiding waste of CO (which for its production has deprived the producer of heat) in the waste gases becomes all the more apparent.

Some precaution is necessary in the procedure of steaming the fuel. It is now the common practice to provide water-sealed ashpans for the furnace, so that ashes

falling through the firebars are quenched, with the formation of steam. At the same time a longer life is ensured for the firebars by the provision of a continuous trickle of water—this giving rise to further quantities of steam. The primary duty of the steam is that of keeping the base of the fuel-bed cool in comparison with the remainder, so that excessive fluxing of the ash is prevented, and the formation of clinker curtailed. Steam in passing up through the fuel is broken up into its elements, the oxygen combining with the carbon in the following manner—

$$C + H_2O = CO + H_2$$

This reaction, being endothermic, deprives the producer of heat; but the heat so lost has been instrumental in generating a further quantity of combustible gases (CO and H_2) which yield up an amount not far short of the loss, when burnt in the combustion chamber and cooled down in the regenerator. What has in reality happened is that heat has been appropriated from the producer at a point where excessive temperatures are to be avoided and has been transferred, with a certain amount of loss, to the portion of the setting where maximum quantities of heat are desired. In this way steaming, in spite of the thermal losses it occasions, has a two-fold value. Owing, however, to the endothermic nature of this reaction (which occurs at high temperatures), the quantity of steam must be curtailed, otherwise the fuel-bed will be inordinately cooled, which may result in the oxidation of carbon to CO_2 in the following manner—

$$C + 2H_2O = CO_2 + 2H_2$$

This reaction, being also endothermic, is depriving the producer of heat for the formation of an inert gas, CO_2. Moreover, the presence of excessive quantities of steam is likely to increase the tendency of some of the CO to undergo oxidation—

$$CO + H_2O = CO_2 + H_2$$

In brief, to take an exaggerated analogy, all attempts at working the producer on conditions approaching those of the water-gas generator (necessarily an intermittent operation, owing to the large thermal losses during gas-making) are to be condemned.

[The practical working of producers and economy of fuel are further discussed in Chapter IV.]

HORIZONTAL BENCHES: GENERAL CONSIDERATIONS

Direct-fired furnaces, in spite of their inefficiency, are still to be found (particularly as stand-byes) in a few of the country works of moderate size. Their chief recommendation lies in the fact that in case of emergency spare units can be put under working conditions in far shorter time than is the case with gaseous settings, thus avoiding the necessity of keeping the latter under slow fires. The original type, however, with air supplies entirely uncontrolled, is now giving way to a more efficient design operated on semi-gaseous lines. This principle is shown in Fig. 17, from

which it will be seen that the air entering under the grate is controlled by dampers, so that a portion of the coke is burnt to CO instead of wholly to CO_2. A further supply of air (also under control) is then admitted above the fuel, so that complete combustion takes place. In this way the supply can be regulated within finer limits than is the case when the whole is admitted under the grate, and the excess of air in the flue gases can be reduced by more than one-half.

Works making up to 100 or 120 million cubic feet per annum usually employ the 10-foot stop-ended retort, and where shovel charging is in vogue this system is

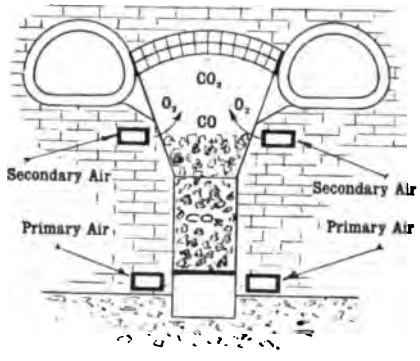


FIG. 17.—SEMI-GASEOUS PRODUCER.

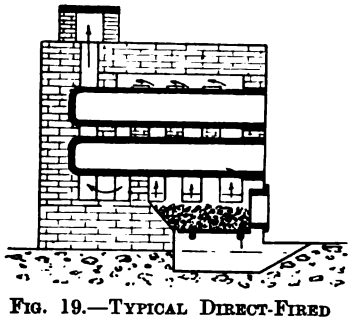


FIG. 19.—TYPICAL DIRECT-FIRED FURNACE.

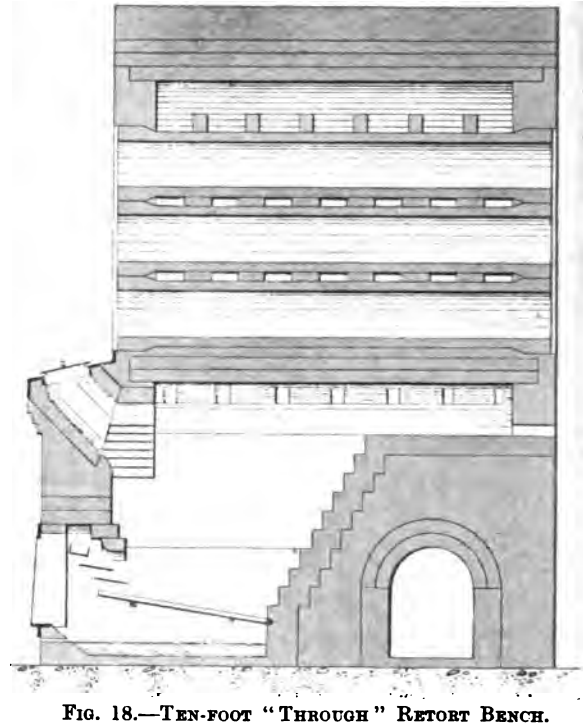


FIG. 18.—TEN-FOOT "THROUGH" RETORT BENCH.

undoubtedly the most suitable. A recent introduction, however, is the 10-foot through bench seen in Fig. 18; whilst typical stop-ended settings are shown in Figs. 19 and 20. The single through bench has the advantage that discharging machinery may be used; and, the back-end of the retort being close up to the retort-house wall, the coke can be pushed direct into the yard. A modern favourite for medium-sized works making from 120 to 200 millions per annum is the 14-foot through retort, which may be suitably operated by some of the present-day types of discharging-chargers.

The following average dimensions are given for the various types of benches with their houses:—

	ft.	in.	
1. Single bench:	1	6	at back of bench.
	12	6	for bench (11 feet 6 inches if retorts are 9 feet long).
	18	0	in front.
	32	0	over-all width inside house.

The height of the bench would be about 11 feet from ground-level, and the height of the house to the eaves 20 to 21 feet.

2. Through bench (scoop charging and no machinery)—
   Bench, 20 feet.
   Each side of bench, 18 feet.
   Total width of house, 56 feet inside.
   Height of bench from top of foundation to top of brickwork, nearly 20 feet for 3 tiers.
   Height of house to eaves (stage type), about 35 feet.

3. Through bench (charging and discharging machinery)—
   Bench, 20 feet.
   Charging side, 23 feet.
   Discharging side, 17 feet.
   Total width of house, 60 feet.
   Height of bench from top of foundation to top of brickwork, 24 feet 6 inches to 26 feet for 5 tiers.
   Height of house to eaves (stage type), 41 feet, with continuous hoppers.
   Height of house to eaves (stage type), 36 feet, with hoppers between roof trusses.

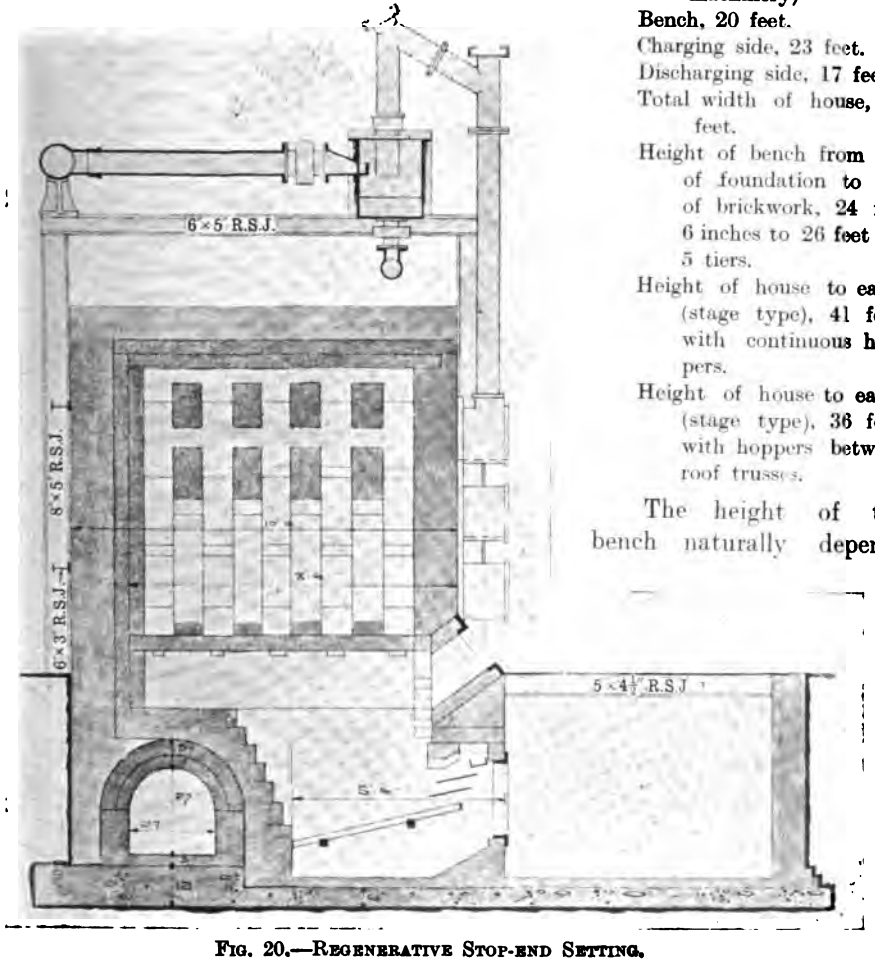


FIG. 20.—REGENERATIVE STOP-END SETTING.

The height of the bench naturally depends

upon the number of tiers in which the retorts are set, and an approximate rule gives an allowance of 29 inches of height for each tier. This gives the distance from charging floor to the soffit of the main arch. Thus for a setting of 10's in two rows of 5 the height to the underside of the arch would be approximately 12 feet. For a setting of 8's in three rows the height would be 8 feet to 8 feet 9 inches. So far as the width of the main arch is concerned the dimensions (from inside to inside of pier walls) are as follows :—

For two rows : 7 feet 9 inches to 8 feet 9 inches, depending on the size of retorts employed.
For three rows : 8 feet 6 inches to 9 feet " " " "

Where shovel or scoop charging is employed, it is inadvisable to have more than three superimposed tiers of retorts, otherwise a movable stage has to be used.

CONSIDERATIONS IN DESIGN OF THE SETTING

The question of the capacity of various units has already been discussed in Chapter I (page 12). In the smaller works the unit is of more importance, owing to the necessity of providing for comparatively small fluctuations in output. For this reason it is common to find arches of varying capacity, as is seen in the retort bench shown in Figs. 21 and 22. In the medium and large sized works the smaller fluctuations can best be coped with by the use of a water-gas plant.

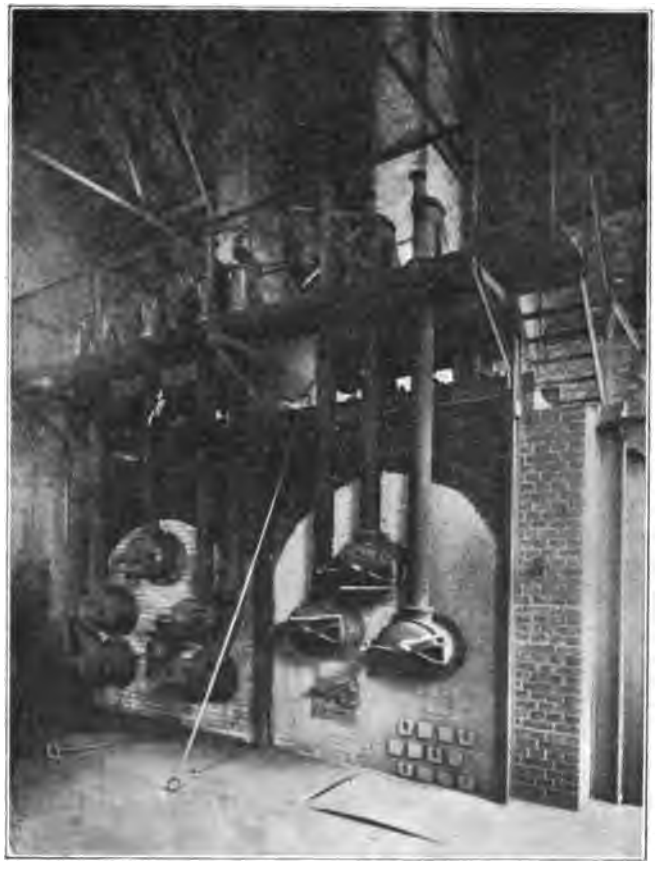


Fig. 21.—Retort Bench with Varying Units.

While the design of the direct-fired setting is comparatively simple, the various portions of the gaseous setting require particular care and experience if the many demands made upon it are to be satisfactorily met. In connection with the direct setting the following points in con-

struction and working may be given separate notice, although many of those hereafter classified under gaseous settings also apply :—

(*a*) Where the longer retorts (9 feet and 10 feet) are employed, attention must be given to the method of heating the back-ends, otherwise the last foot or so will be dull in comparison with the remainder. This is best coped with by building a special double chamber at the back-end, thus ensuring the thorough circulation of the gases around the retort at this point.

(*b*) The air supply should be regulated, and split up into a primary and secondary supply (semi-gaseous) where possible.

(*c*) Steaming the fuel-bed should be reduced to a minimum. In this type of furnace the waste products escape at high temperatures, and the heat required to

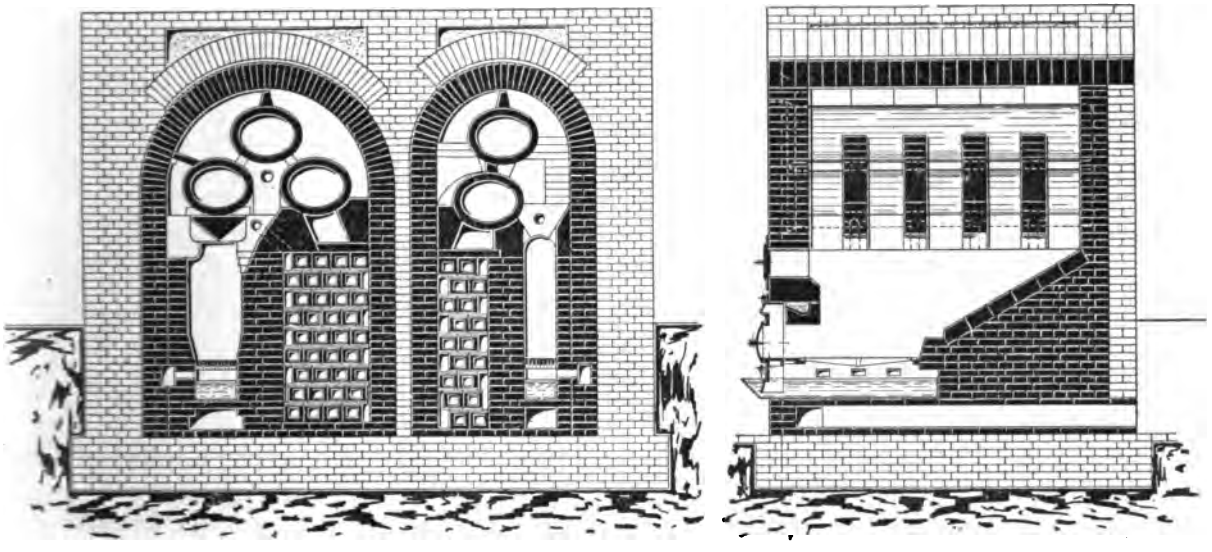


FIG. 22.—REGENERATOR RETORT BENCH WITH VARYING UNITS.

raise the steam to the temperature of the setting is appropriated from the heat produced by the combustion of the coke—hence the steam occasions a direct loss. This also applies to the generator system, but does not occur to nearly the same extent in regenerator settings, where the waste products are cooled considerably before escaping.

Water-cooled firebars should be avoided.

(*d*) All flues must be accessible for cleaning while the setting is at work.

(*e*) The possibility of short-circuiting between the flues—a common fault with these settings—must be provided against.

(*f*) The loss of heat through the walls of the furnace by radiation is proportional to the size of the furnace ; thus the furnace having the smallest heat-radiating surface will be the most economical.

(*g*) The further back the actual fire stretches, the better will be the heating of

the back of the retorts ; on the other hand, very long grates are difficult of access for cleaning, etc.

(*h*) If a deep fuel-bed is employed CO will be formed, and escaping unburnt will account for considerable loss. In the smaller grates 12 inches of fuel depth is ample. It should not in any case exceed 18 inches, unless, of course, a supply of secondary air above the fuel is arranged for. This point is often difficult to impress upon the country stoker, as charging the furnace little and often entails considerably more trouble.

(*i*) The front of the fire (above the firebars) must either be sealed with a plate or breezed up so that all air enters beneath the firebars.

(*j*) The furnace linings should be isolated from the remainder of the brickwork, and not bonded in in any way. The wear and tear with this type of furnace is extremely heavy, and the furnace requires frequent re-lining.

(*k*) The stop end of the retort frequently breaks away after the bench has been working for some time, and as bricks will then have to be inserted it is as well to brick up the end (4½ inches) before the retort is put to work in the first place.

(*l*) When starting up settings care must be taken to avoid explosions. The chances of explosions occurring in direct settings are remote, but the experience is by no means unknown. (For further information, *see* page 87 *et seq.*)

GENERATOR AND REGENERATOR SETTINGS

The essential difference between generator and regenerator settings is in the means employed for circulating the waste gases and, in the latter type, for extracting the maximum quantity of sensible heat from them before their escape. In the generator type the main waste-gas flue travels along the top of the main arches, with the chimneys carried up at intervals, whilst in the regenerator system the waste

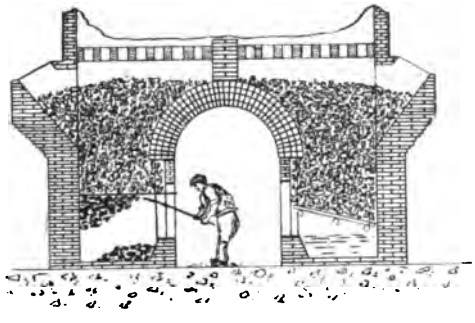


FIG. 23.—DOUBLE FURNACE.

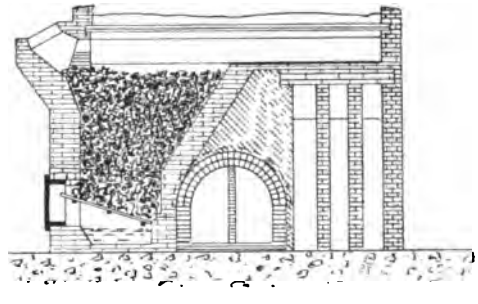


FIG. 24.—SINGLE FURNACE.

flue generally runs longitudinally through the entire bench, practically at foundation-level. Another important distinction is that with generator settings a double furnace (Fig. 23) is usually employed, whilst the single furnace (Fig. 24) is now exclusively used with the regenerator bench. The latter embraces the advantages of reduced

labour in charging and clinkering, more effectual control of heats, less wear and tear, and considerably improved working conditions for the men. Generator settings are seldom used in conjunction with " through " retorts.

So far as the design of the modern regenerator furnace is concerned, a typical

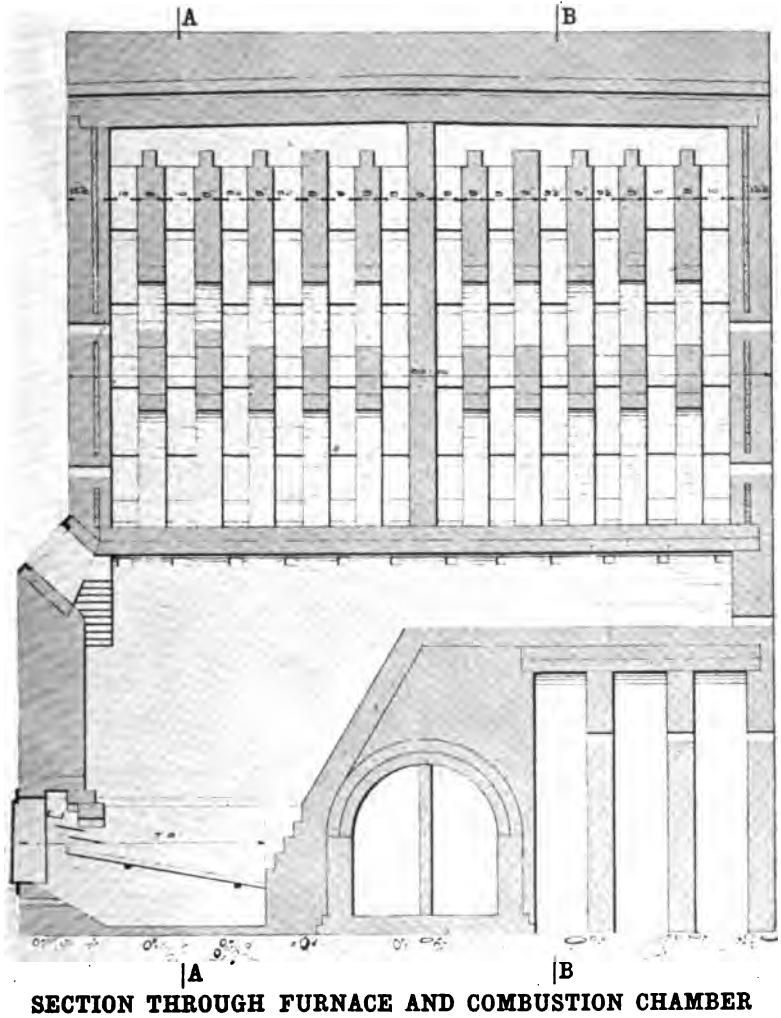
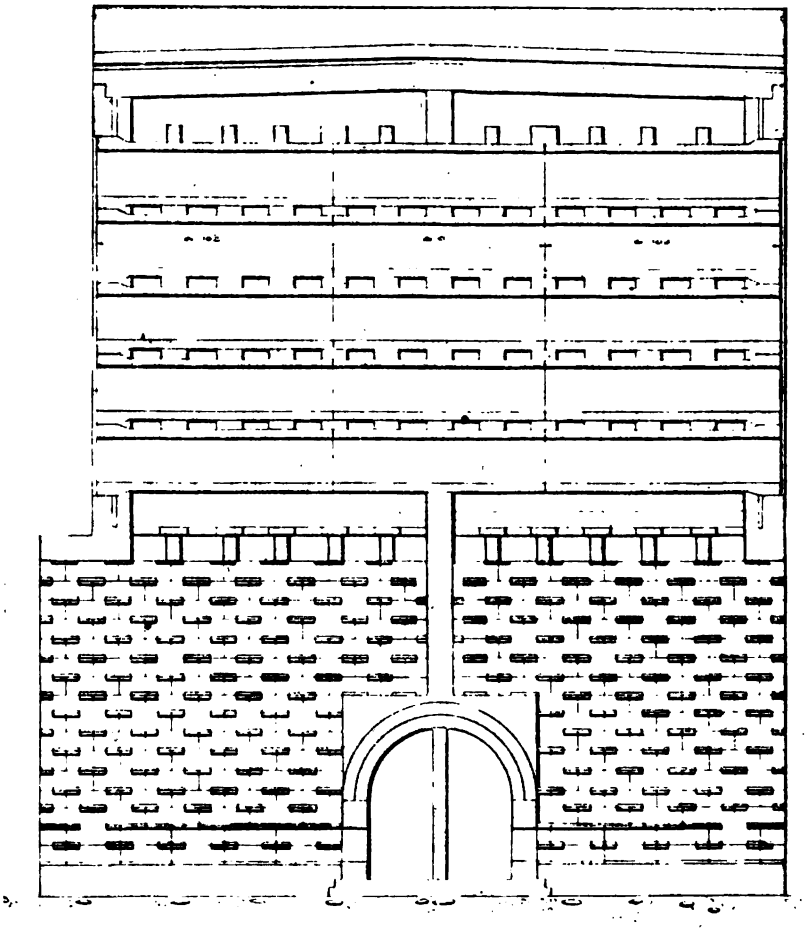


FIG. 25.—A TYPICAL HORIZONTAL REGENERATOR RETORT BENCH.

working drawing is shown in Figs. 25, 25A and 25B, whilst a sectional diagram of the same type of setting is given in Fig. 26. The various portions of the setting and the considerations to be kept in view in order to ensure long life and effective working are dealt with under their respective headings.

(*a*) Main Arches

The stability of the bench must be ensured, and the tendency of the pier walls to lean slightly from the vertical (due to the thrust of the main arches) must be checked by the erection of substantial end walls and suitable bracing. When the

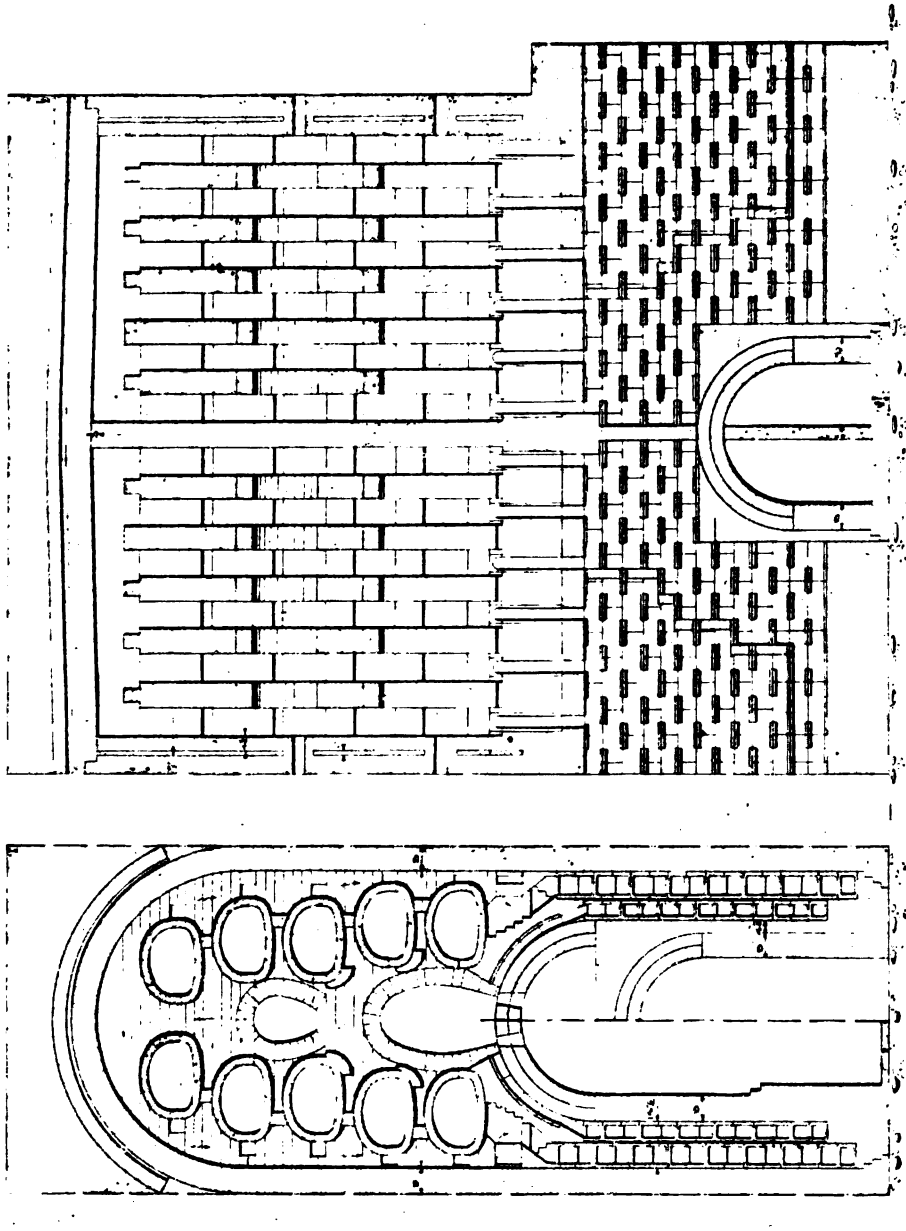


SECTION THROUGH WASTE GAS FLUES

Fig. 25a.

bench contains more than (say) four beds, these buttress walls should never be built less than double the thickness of the ordinary pier walls, whilst it is only necessary to construct the inner 9 inches of firebricks. For reasons mentioned later (*see* page 154) an ordinary hard stock brick of good quality and shape is perfectly suitable and desirable for the remainder of the work.

As a general rule an 18-inch wall between the arches will suffice for all types of settings, and the two-and-a-half brick wall occasionally seen is wholly unneces-



SECTION THROUGH SECONDARY AIR FLUES

SECTION on AA SECTION on BB

FIG. 25B.

sary. Such walls are, of course, entirely constructed from firebricks, these being carried up round the main arches to a depth of 9 inches. Beyond this, any further

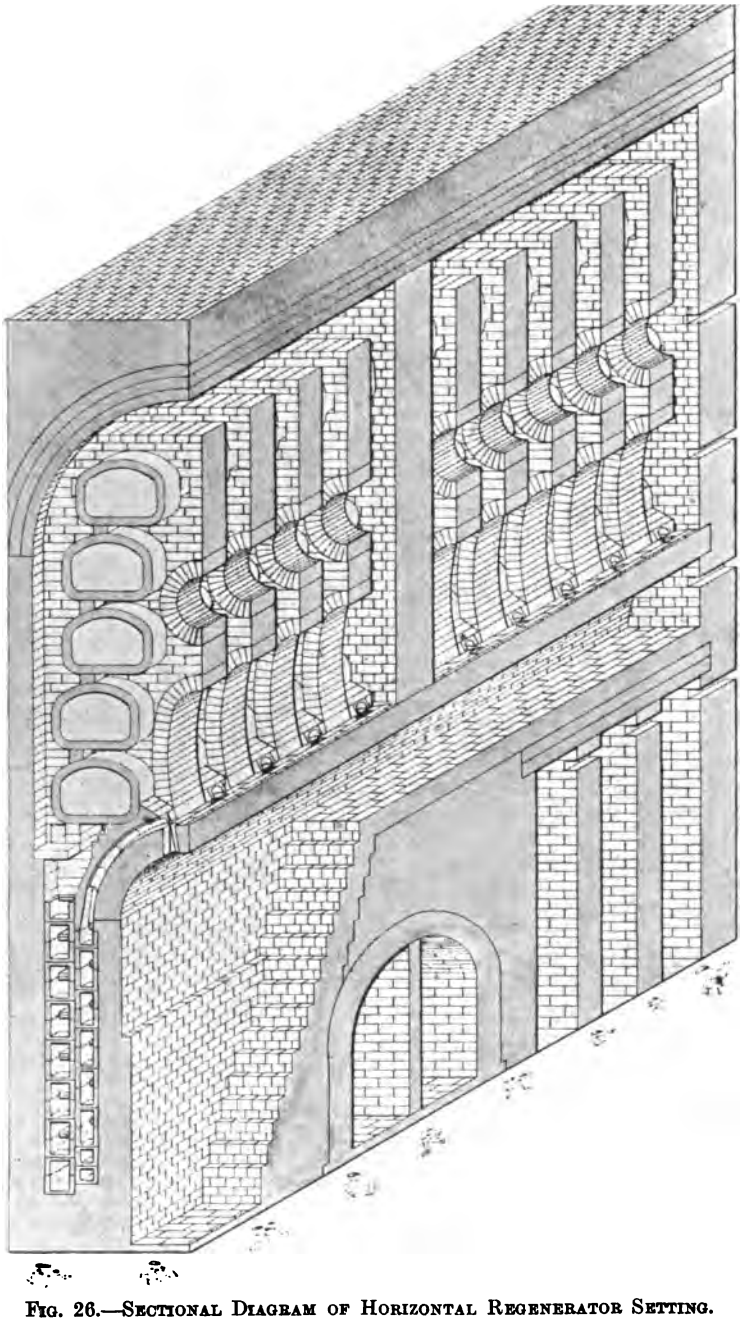


FIG. 26.—SECTIONAL DIAGRAM OF HORIZONTAL REGENERATOR SETTING.

brickwork required for filling up the spandrils, etc., may be of ordinary stock-work or, if preferred, old firebricks well cleaned. A reveal (as shown in Fig. 27) should

be left in the pier walls and arches so that a tight joint is obtained when the front wall goes up.

The semicircular main arch is the ideal, as it accounts for practically no horizontal thrust on the side walls. With settings of two vertical rows the semicircle should always be employed; but the greater width necessary with three or four vertical rows makes the use of such an arch somewhat inconvenient. In such cases elliptical or segmental arches are often erected, as in this way excessive headroom above the top tier of retorts is avoided. Care must be taken, however, to see that decidedly flat arches, liable to failure, are abstained from. A generally recognized rule is to the effect that no arch should have a radius of more than 7 feet 6 inches. Many designers will hear of nothing else but a semicircular arch, whatever the type of setting. It is maintained that the excessive headroom does not matter in the least, and, if necessary, can be tiled in and isolated. The increased cost entailed is comparatively insignificant.

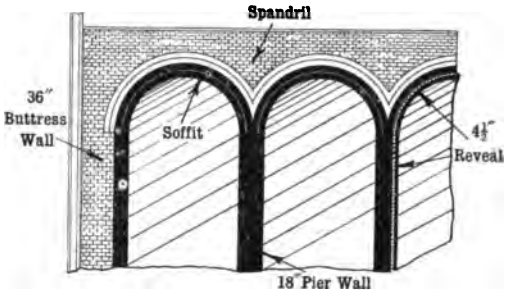


FIG. 27.—MAIN ARCHES FOR RETORT SETTINGS. THE BLACKED PORTION INDICATES FIRE-BRICK.

All types of arches are generally built from concentric rings of brickwork, although a growing (but more expensive) practice is to employ special radius blocks. When the brick arch is used, however, there should never be less than three rings, as it is impossible to prevent some sagging of at least the lowest ring after the arch has been in operation for some time. To overcome this drawback the barrel-arch with a camber in both directions (Fig. 28) has been introduced with success, but owing to increased expense must be looked upon as a luxury. A simple and effective means of preventing the dropping of the inmost ring is to stay up the soffit of

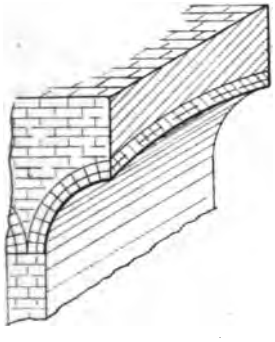


FIG. 28.—BARREL-SHAPED SETTING ARCH.

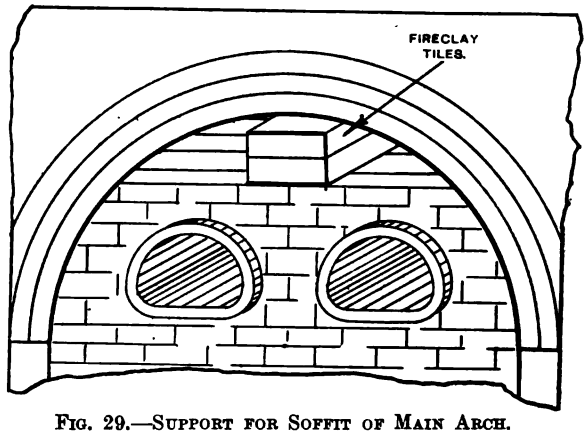


FIG. 29.—SUPPORT FOR SOFFIT OF MAIN ARCH.

the arch by means of tiles supported from the cross-walls of the setting (Fig. 29). It should, however, be seen that expansion of the work below is allowed for, by leaving a space between the top of the tiles and the soffit of the arch. Two inches will usually answer the purpose. The difficulty, however, lies in gauging the amount of expansion, so that when the setting is heated up the soffit just rests on the tiles. Obviously, if there is a space between the two the tiles are useless, whilst if over-expansion takes place they are actually harmful.

In America, some attempt has been made to reduce the losses of heat from radiation by leaving cavities around the main arches, or by employing special channel blocks (Fig. 30). The practice, however, cannot be recommended, as the stability of the work is seriously affected, and radiation losses will not be excessive if the brickwork is carried up at least 18 inches above the top of the arch rings. As a further precaution it is as well to plaster the top of the bench with a thin layer (2 inches) of some non-conducting material. This can be effectively made from waste rope dust and rough asbestos composition composed of ten parts of the former to one part of asbestos. The rope dust costs about 15*s.* per ton, the asbestos £5 10*s.* and the work, including the labour, can be carried out for 3*s.* 6*d.* per square yard.

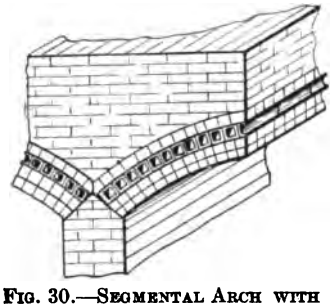


FIG. 30.—SEGMENTAL ARCH WITH AIR CHANNELS.

An objectionable practice, which is happily dying out, is that of filling up the spandrils of the main arches with sand and putting a paving of bricks on the top of this. Far from preventing radiation, the sand, owing to its close-lying nature, is always accompanied by excessive losses in this respect; and in time, when the work gets old, the sand is likely to drain through crevices, leaving hollow spaces in the spandrils and giving trouble in the settings owing to its low fusing point.

(*b*) THE PRODUCER

Through retort benches should in all cases be fired with the single rather than the double furnace, as in this way a saving of from 10 to 15 per cent. in fuel consumption can be looked for. The primary consideration is that of ensuring ample depth of fuel-bed, so that the reduction of carbon dioxide to carbon monoxide may effectively take place. In the larger regenerative settings of 8's and 10's it is preferable to allow for not less than 7 feet from the mean level of the firebars to the springing of the producer arch, although in the smaller units this will often be no more than 5 feet. As regards shape, the internal producer is always rectangular. Although on certain scientific grounds it should be square (due to the fact that of rectangular figures the square has the smallest perimeter for a given area, thus exposing the minimum amount of wall surface), it is commonly constructed with the front width about half the distance which it extends backwards at the base. The reason for this is that construction is facilitated, a better distribution of producer gas results, ample room is left for the regenerator device, and the front wall

area is comparatively small. This last is an important point, in that heat radiating through the wall is lost, whereas in the longer side walls it is partly picked up by the inflowing secondary air and recovered. Further considerations which must receive attention are the following:—

(1) The producer lining should be entirely separate from the main body of the brickwork. The wear and tear on this portion of the setting is heavier than that on any other portion, and although a well-built and substantial lining will remain in workable condition for about 600 to 800 days, minor repairs are often necessary every year. Shutting down and restarting, however, is to be avoided as far as possible, owing to the undesirable effect on the working life. The false cheeks to the producer may be built up of a 4½-inch or 9-inch wall. The latter is preferable, and the bricks should be laid all "headers," so that considerable wear can take place without the bond of the work being broken.

(2) The lowest point of the charging door frame of the producer should be no higher than the soffit of the furnace arch, and the frame should be sloped at such an angle as to enable the coke at the back of the furnace to be seen, and to be reached with a rake.

(3) The lower portion of the producer should be slightly narrower than the upper portion. That is, at a point about level with the top of the furnace frame the brickwork should be set back 2¼ inches at the sides. This will prevent the short-circuiting of primary air up the sides of the fuel-bed.

(4) The primary air should preferably be admitted through slides in the furnace door, and not by means of channels passing through the brickwork at the side of the furnace. Such channels usually give trouble by choking up, whilst short-circuiting of the primary air up the front of the fuel-bed may be avoided by "breezing up."

The general practice is to build up the producer with parallel side walls, a semicircular furnace arch being thrown over these (Fig. 25B). In some cases additional strength is given to the producer by arching out the side walls as in Fig. 31, but the advantages accruing from this arrangement can scarcely be said to compensate for the increased cost. The widening out of the furnace in this way also prevents the short-circuiting of air through the fuel-bed. One or two sets-off of bricks should be arranged for at the back of the producer, and the remaining work taken up at a wide angle with the horizontal. Whatever the shape of the producer, the front wall should be of 18-inch thickness, and there should not be less than 9 inches solid work between the side walls of the furnace and the regenerator flues.

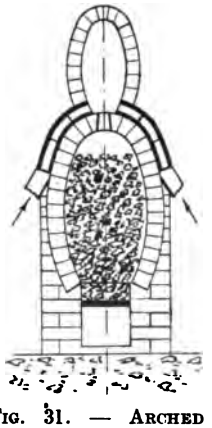


FIG. 31. — ARCHED PRODUCER.

(c) GRATE AREA

The recognized modern rule is that of allowing $\frac{1}{10}$ square foot of grate area for each lineal foot of retort in the setting, and for effective working this should be

looked upon as the irreducible minimum. For a through setting of ten retorts the rule gives a grate area of 20 square feet. There is little doubt that the producer now used in conjunction with the continuous vertical retort owes its economy in part to the increased grate area allotted. In the Woodall-Duckham system this amounts to as much as 28 square feet for each producer, or rather more than ¼ square foot per lineal foot of retort in the bench. Mr. Thos. Glover has stated that with certain coals a grate area of ¾ square foot per 10 feet 6 inch run of retort is sufficient, but with other coals, containing different proportions of lime and iron in the ash, the clinker is difficult to remove. Another rule is that of allowing 1 square foot of area for each 8 lb. of coke consumed by the furnace per hour. This basis, however, is not altogether satisfactory, as the fuel consumption is arrived at by guesswork, and necessarily varies with the type of coke in use.

(*d*) Flue and Chimney Area

The retort-house chimney in large houses varies from 50 to 70 feet in height. The chief considerations to be kept in mind are that of taking it well above any adjoining buildings, and that down-draughts and varying winds are avoided. With direct-fired and generator furnaces it is usual to support the chimney from the top of the bench and to run the main waste-gas flue directly into it. With the regenerator setting, however, the chimney is usually sprung from foundation-level, and should preferably be entirely distinct from the bench. So far as its constructional features are concerned, the cross-sectional area is the most important, and must in all cases be adequate. The usual rule, which may be applied with perfect reliance, is to allow 1½ square inches of area per lineal foot of retort in *all settings dependent upon the flue and chimney.* Thus, suppose a bench consisting of eight settings of "tens" is to work on to a common flue and chimney—

The length of retort in each setting is 200 feet.

The length of retort in eight settings is 1,600 feet.

The chimney area required is 1,600 × 1½ square inches, *i.e.* 2,400 square inches, or 16⅔ square feet.

With large units of through settings 75 per cent. of this is sufficient.

Another rule (due to Herring) is that of allowing 40 square inches per ton of coal carbonized per diem by the whole bench of retorts dependent on the chimney. The following formula (Brooke) is also sometimes used :—

$$A = \frac{5W}{\sqrt{H}}$$

Where A = area of chimney in square feet.
H = height of chimney in feet.
W = weight of fuel burnt per minute, in lbs.

In any case, when a shaft is to be erected it should be based upon the first of the rules here given, and the last named may be used as a means of checking. It is inadvisable to connect a chimney to a greater number of beds than ten, as above this (at any rate for settings of 10's or 12's) its dimensions become somewhat

unwieldy. Circular shafts, except for some vertical installations, may now be said to be things of the past, and the rectangular chimney with external batter is most commonly seen. A typical design of this style of shaft is seen in Fig. 32. It will be noticed that a square base 10 feet in height is provided. Some ornamentation (such as oversailing courses, plinths, or panelling in different coloured bricks) is usually added. The batter commences immediately above the square base, and is usually run in the ratio of 1 to 36 or 1 to 40. A point to remember is that the calculated chimney area refers to the area at the base of the shaft, and the design should be such that, in spite of the reduction of thickness of the brickwork, the cross-sectional area at the summit is the same. In Fig. 32 a batter of 1 in 40 gives an over-all reduction in total width of 3 feet, and at both top and bottom the internal dimensions are similar, namely 3 feet 9 inches square.

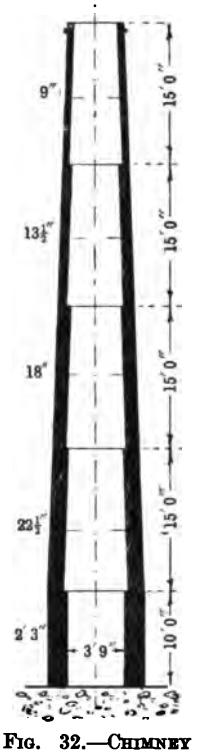


FIG. 32.—CHIMNEY WITH EXTERNAL BATTER.

So far as the thickness of chimney walls is concerned, the following typical instances for various heights are given :—

(*a*) 68 feet high.
Brickwork : 1 foot 10½ inches for 12 feet.
1 foot 6 inches for 16 feet.
1 foot 1½ inches for 20 feet.
9 inches for 20 feet.

(*b*) 65 feet high.
Brickwork : 1 foot 10½ inches for 12 feet, reducing to 9 inches at top. Outside batter 1 in 36.

(*c*) 58 feet high.
Brickwork : 1 foot 10½ inches for 11 feet.
1 foot 6 inches for 14 feet.
1 foot 1½ inches for 16 feet.
9 inches for 17 feet.

A small proportion of chimneys is now to be found in which the brickwork is reduced to 4½-inch for some distance in the upper length. It must be strongly emphasized, however, that such design is to be rigidly avoided, the more so in retort-house shafts, where wind and heat have both to be withstood. Chimneys of this description are occasionally to be met with in which no external batter has been provided, the walls running up vertically from base to top. For instance, a group of retort-house shafts is known which are constructed as follows : The shafts are 70 feet in height, the first 30 feet being 13½-inch brickwork, the next 20 feet 9-inch brickwork, and the final 20 feet 4½-inch work. In the 4½-inch portions the corners are constructed of 6-inch work for increased stability. The effect of such design on chimney area is well illustrated by reference to Fig. 33. The effective area at the base is 14 square feet ; whereas at the 9-inch work it has been increased to 27½ square feet, or nearly double.

Retort-house chimneys are usually braced for their entire height, the most general method being to run angle-iron up each corner, the irons being held in posi-

tion by tie-bars at intervals of about 6 feet. The shaft used in conjunction with regenerator settings may be centrally divided by a 4½-inch wall in the same manner as the main waste-gas flue. It is always advisable to leave inspection doors at the base of the shaft, so that the condition of the waste-gas flue can be readily seen during working, and a vacuum gauge inserted; whilst provision should be made for a cleaning door, so that dust, etc., may be removed during stoppage. The same door is also useful for the insertion of a coke bucket when starting up, in order that a natural draught may be stimulated. On the Continent it is occasionally the practice to erect a distinct chimney for each bench of retorts. It is claimed that in this way each furnace may be worked independently, whilst with the common chimney one furnace may influence another. The idea, however, is confined almost wholly to stop-ended retort settings.

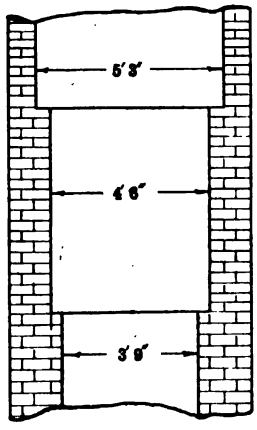


FIG. 33.—SHOWING OBJECTION TO UNTAPERED CHIMNEY.

As regards the bricks for the construction of retort-house chimneys, where stock-work is used a firebrick lining should be provided for the lower half. Nowadays, however, it is far more common for the whole chimney to be built of firebricks, in which case no lining is necessary.

Natural draught depends for its action on the difference of density between the cold air surrounding the shaft and the warm products of combustion. Moreover, the quantity of gas drawn up by a chimney increases in proportion to the square root of the height of the chimney; consequently any increase in height produces only a comparatively small change in the quantity of gases drawn off. As a matter of fact, a shaft creates the best draught when the temperature of the issuing gases differs from the atmospheric temperature by 523° Fahr. Accordingly, when the difference between the two temperatures is greater than this the draught is not so good, and a larger and useless loss of heat takes place. On the other hand, the heat carried off by the escaping gases must not all be considered as loss, for a certain temperature is necessary for the creation of a natural draught.

(*e*) REGENERATION

Regenerators and generators of various types may be primarily classified as follows:—

Ordinary generators.

(1) Primary and secondary air supply both unheated.

(2) Primary supply unheated. Secondary heated, but at expense of producer.

(3) Primary and secondary supplies both heated at expense of producer.

Regenerators.

(1) Primary unheated. Secondary heated by sandwiching between producer and waste gases. This is by far the commonest type.

(2) Primary unheated. Secondary heated by sandwiching between two streams of waste gases. In this way the producer is not deprived of heat.

(3) Primary unheated. Waste gases sandwiched between two streams of secondary air.

(4) Primary and secondary supplies both heated by waste gases.

(5) Primary or secondary air initially heated by the extraction of sensible heat from the hot coke in the retort. That is to say, in reality the coke leaving the retort is quenched by the ingoing air supply. This arrangement is only practicable with vertical retort systems of the continuous type.

With regard to the merits of the various systems, in the case of the ordinary generator no use is made of the heat in the waste gases, and the secondary or primary air is raised in temperature entirely at the expense of the producer. Compared with no initial heating of the air supply the system does, however, effect some economy in that the air appropriates part of that heat which would otherwise be lost by radiation. It is in connexion with this point that so much diversity of opinion exists with regard to regeneration by means of waste gases. Many authorities assert that to admit secondary air through channels adjacent to the producer (Figs. 26 and 41) is uneconomical, and for this reason provision is made for entirely encircling the air with waste gases as in Figs. 37 and 40. In support of this theory Brooke gives the following figures:—

	Percentage Efficiency of Regenerator.	Percentage of Total Heat in Secondary Air abstracted from Producer.
Outside producer	100	—
Inside producer. Air flue sandwiched between waste gases	90–95	5–10
Waste-gas flue between air supplies	80–90	10–20
Air flue between side of producer and waste-gas flue	70–80	20–30
Air flue by side of producer	6	94

Too much attention must not, however, be paid to this point; and it must be remembered that heat will inevitably pass outwards from the hot producer walls and cause loss by radiation. Thus, if the secondary-air flue is adjacent to the producer, it will undoubtedly account for a reduction in the loss from this source. In practical working the distinction between the two types (1 and 2) cannot be said to have a noticeable effect on fuel consumption.

When choice of a regenerator is to be made consideration should, in turn, be given to the following items:—

(1) The surface contact between the regenerator flues and the secondary-air flues must be ample.

(2) Every precaution must be taken to ensure that no short-circuiting takes place. According to the construction of the regenerator this may occur :—

(*a*) Between secondary-air flues and waste-gas flues.

(*b*) Between producer and secondary-air flues.

(*c*) Between producer and waste-gas flues.

(3) There must be ample facilities for the removal of dust, etc., from both waste-gas and secondary-air flues. In some types of regenerator no cleaning is possible until the whole is demolished.

(4) Means for regulation of the secondary air should be provided. It is frequently found that the currents of air to the various "nostrils" vary in quantity to a considerable extent. For this reason dual or multiple regulation is arranged for in some types (*see* Figs. 25B and 40).

(5) The baffling arrangement in the secondary-air flues should not be too involved, otherwise an excessive draught will be necessary in order to pull the requisite quantity of air through. High velocity of draught means too rapid travel of the waste gases, which consequently leave the setting before effecting the maximum exchange of heat. It is difficult to give any figure for the thickness of regenerator blocks, and a medium has to be struck so as to afford both good conductivity and stability.

Types of Regenerators

The principle of operation of regenerators is best understood by reference to diagrams, and several illustrations of the most notable types are here reproduced. One of the best-known systems which came into use in the earliest days of regeneration was the Klönne. In this the interchange of heat was brought about by the employment of special blocks as shown in Fig. 34. In the Gibbons and Masters' system slotted fireclay boxes, moulded out by machinery, are erected side by side in vertical tiers so that no straight joints occur. This system has the advantage of being particularly simple, only necessitating the use of the one-standard type of block (Figs. 35 and 36), whilst the wall-thickness separating waste gases and secondary air is reduced to 3 inches with perfect immunity from short-circuiting.

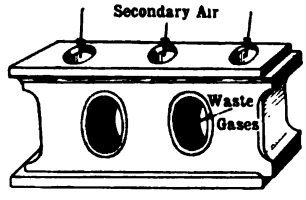


Fig. 34.—Klönne Regenerator Block.

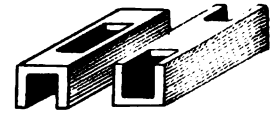


Fig. 35. — Gibbons & Masters' Regenerator Blocks.

In Drake's system rectangular fireclay tubes (Fig. 37) are employed, the waste gases travelling backwards and forwards through these, whilst the secondary air traverses upwards around the outside of the tubes. The tubes are placed end to end, all joints being covered by bricks for the purpose of avoiding by-passing. If through the movement of brickwork by-passing does take place, it can at once be seen and remedied through the front wall of the regenerator. This is done by means of a "paddle" and patching

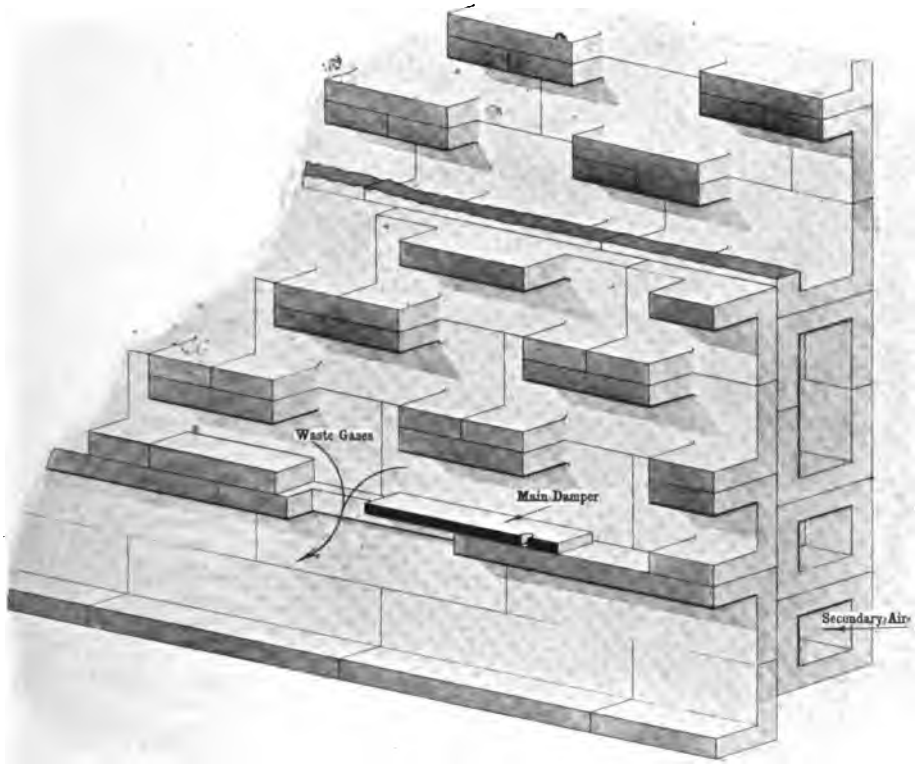


FIG. 36.—GIBBONS & MASTERS' REGENERATOR SYSTEM.

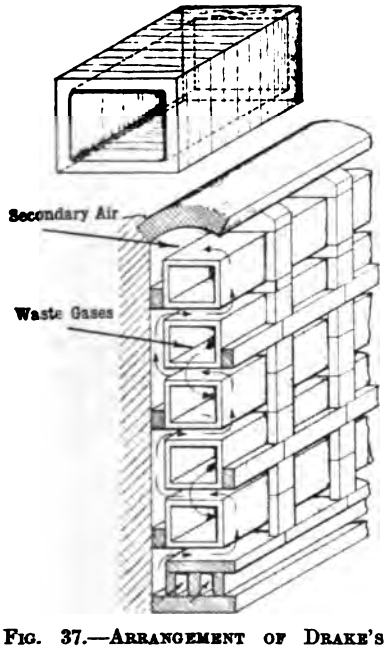


FIG. 37.—ARRANGEMENT OF DRAKE'S PATENT TUBULAR REGENERATOR.

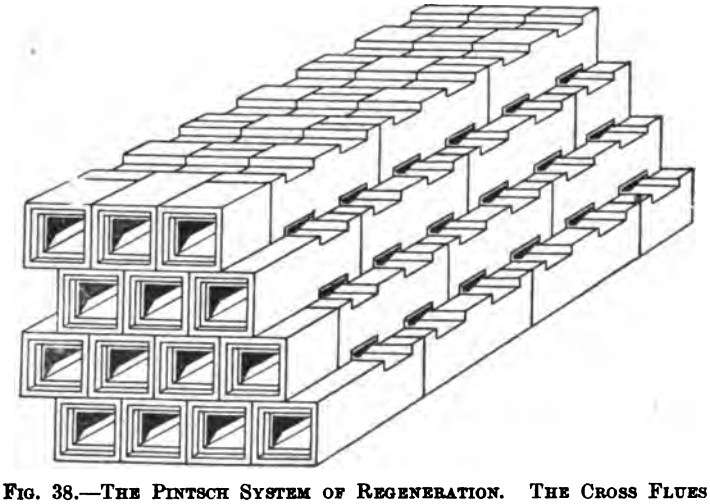


FIG. 38.—THE PINTSCH SYSTEM OF REGENERATION. THE CROSS FLUES ARE FOR SECONDARY AIR, AND THE LONGITUDINAL FLUES TAKE THE WASTE GASES.

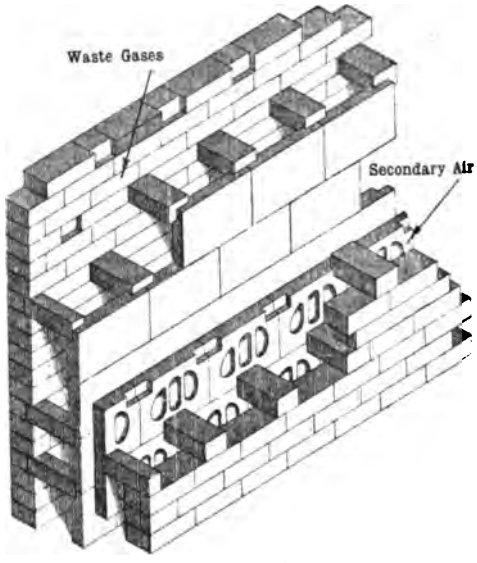


FIG. 39.—BROWN'S REGENERATOR.

material, in the same way as with a cracked retort. As regards the supply of secondary air, each vertical section is absolutely distinct from inlet to outlet, therefore under control, and the quantity at any point along the length of the combustion chamber can be regulated at the secondary-air inlet slide.

A Continental type of regenerator is shown in Fig. 38. In this pattern the walls separating the hot gases and air are reduced to a minimum as regards thickness, and special tubular fireclay bricks are employed. These bricks, placed lengthwise to the furnace, have transverse grooves on the upper and lower outer surfaces and, when put together, form cross-flues between the individual layers. The secondary air, in an ascending stream, passes outside the tubes and through the cross-flues, the waste gases travelling down from the furnace through the tubes. The shaped bricks are rebated at their ends, thus avoiding leakage between the flues.

Brown's patent regenerator is shown in Fig. 39. Ordinary sized firebricks fitting into rebates in the special tiles are used for staying the vertical walls. In building the flues the "bed" and "cross-joints" of the tiles are broken in both directions. The staying bricks do not extend more than half-way through the tiles, so that in the event of one tile breaking, short-circuiting does not take place. Brooke's system (Fig. 40) is

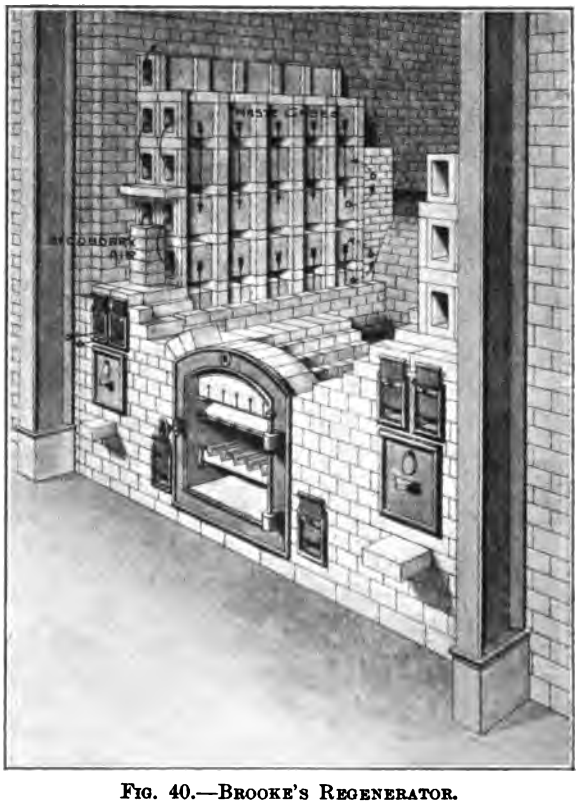


FIG. 40.—BROOKE'S REGENERATOR.

another in which contact is arranged for by tubular means. It differs from types given in Figs. 37 and 38, however, in that in this case the secondary air travels inside the tubes, the waste gases circulating around the outside. The ingoing air travels backwards and forwards in a zigzag direction, and is admitted at two places on each side of the furnace front, and in four similar places at the back of the bench, so that there are eight inlets in all. The air passing through the various series of horizontal flues is kept entirely distinct from the air travelling in the adjoining series; thus the supply to the various portions of the combustion chamber is under control. The waste gases, after leaving the setting, pass vertically downwards, and are kept in separate streams until they reach the bottom of the regenerator flues, when they enter a common channel. At the bottom of each separate compartment a damper enables any one of the streams to be controlled. In the illustration given, the amount of direct contact surface between the waste-heat and the secondary-air flues is 434 square feet.

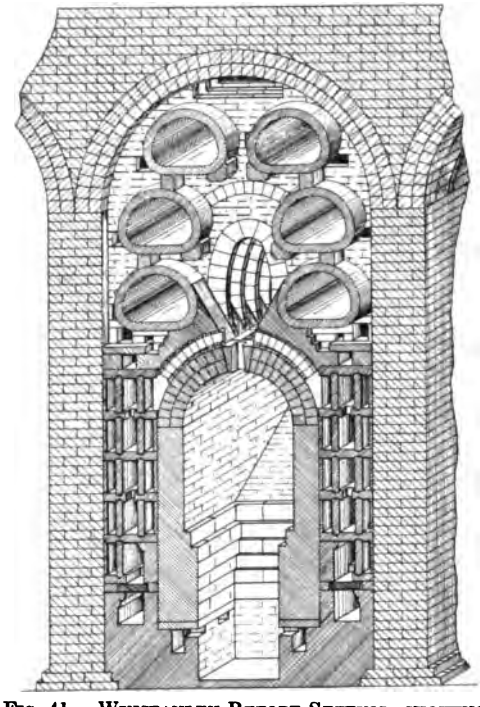


FIG. 41.—WINSTANLEY RETORT SETTING, SHOWING SYSTEM OF REGENERATION.

An illustration of the Winstanley regenerator is given in Fig. 41. The chief point to notice about this type is that the secondary air is taken in in two distinct streams, one on each side of the waste-gas channel, so that the maximum heat is extracted from the hot products. It will be noticed that the inner stream of secondary air is sandwiched between the waste gases and the producer, whilst primary air is admitted through side channels.

It is a striking fact that few standard English settings embrace facilities for heating the primary air as well as the secondary. Such systems are more frequently met with on the Continent, where many complicated arrangements are introduced. From an analysis of fuel results, however, it appears that attention to the practical points of design is of greater value than purely theoretical refinements.

(*f*) THE GENERAL ARRANGEMENT OF THE SETTING

This is, in the first instance, entirely dependent upon the capacity of the unit in question. Small works have, of course, to take up the small fluctuations in demand by setting down units of varying capacity. Although in rare instances it is done, it is not advisable to work a portion of an arch during slack periods, as fuel

consumption is unavoidably increased. If, however, there is no other means of regulating the output, it will be found preferable to work the retorts in one vertical row. The damper on this side of the setting is then opened and that on the opposite side closed, so that the furnace gases are pulled around those retorts in operation. The greater the number of retorts to a bed, the lower (*pro rata*) will be the fuel consumption. Hence settings of twelve have come into fairly extended use. One of the first considerations—of particular moment in cases where land is expensive and the quantity limited—is the productive capacity per square foot of area. The highest yield in this respect is given by the settings of ten retorts in two vertical rows—commonly known as the Bishop of London's bench. The output necessarily varies with the size of retorts, but may be taken, on the average, as 200 to 250 cubic feet per diem per square foot of ground area. This figure is based on the outside dimensions of the retort house and 24 inches × 16 inches through retorts. For a setting of 8's in three rows the capacity would be reduced to 150 to 180 cubic feet per diem per square foot. For vertical retorts the figure (according to the system) may be as much as from 350 to 475 cubic feet per square foot.

The disposition of the retorts in the setting must be such that the heating of each one is as uniform as possible. In settings of two vertical rows this is more easily assured than with three vertical rows, as with the latter, the retort immediately above the combustion chamber has to face the fiercest portions of the flame. In a scientifically constructed setting there is no reason why the average temperature of any of the retorts in that setting should differ by more than 150° Fahr.

Under all circumstances "local heating" must be avoided. This is said to be taking place when certain defined portions of the setting are under considerably greater heat than the remainder. The term really applies to the differing sections of the bench; for instance, we do not speak of a combustion chamber being subjected to local heating merely because its temperature is greater than that of the remainder of the setting. If, however, one section of this chamber were considerably hotter than the remainder, the hotter section would be giving rise to local heating. The effects of this derangement are very often seen when retort doors are opened—rings of dull red colour encircle the retort in contrast to the white heat of the remainder. This is indicative of bad spacing of the "nostrils," or of stoppage of one or more of these; but, beyond choking up by dust or by "drippings" from the upper portion of the bench, the cause of local heating can usually be attributed to constructional defects or to inferior design. The following considerations may be set down as being among the more important items to be kept in mind when designing the upper portions of a setting:—

(1) The combustion chamber should be of ample size, so that sufficient space is allowed for the mixing of the air and gas.

(2) The "nostril holes" must be so spaced out that they come midway between the cross-walls of the setting and the combustion chamber.

(3) The air and producer gas should not come together too closely, and should not meet at right angles. The effect of meeting in this way is that too thorough mixing takes place, and short flames of small volume are the result (*see* Fig. 42).

(4) The shape of the nostrils is of importance; they should be tapered in section (Fig. 42), the smaller width being at the top. In this way any lumps or dust falling from above will drop through the nostril instead of lodging in it.

(5) The secondary air on both sides of the setting should be under dual control at least, or preferably the supply to each nostril should be capable of regulation. It is frequently found that the air has a tendency to rush towards the centre nostrils of the furnace arch, this giving rise to irregular distribution of heat and dull mouth-pieces.

(6) The "nostrils" should be kept low in comparison with the bottom retorts. If they are above the base of the lowest row of retorts, the latter will be insufficiently heated.

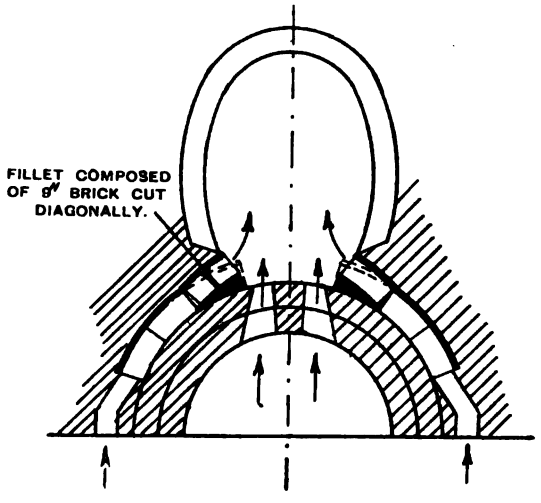


FIG. 42.—DEFLECTING SECONDARY AIR SO THAT FURNACE GASES MEET IN A PARALLEL DIRECTION. DOTTED LINE SHOWS USUAL POSITION OF CHANNEL BLOCK.

(7) For settings containing two vertical rows of retorts the direction of discharge of the producer gas should be vertical (Figs. 43 and 44). For three rows the "nostrils" should point outwards. In this way more effective distribution of heat is assured, whilst the centre retort is not subjected to a direct cutting heat.

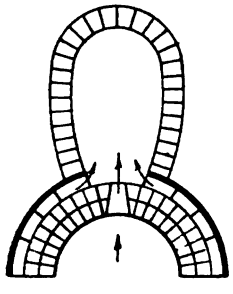


FIG. 43.

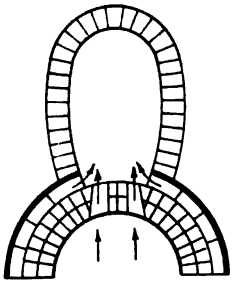


FIG. 44.

(8) Retorts are far less liable to "local heating" when set in tiers of two's. Thus if a setting of eight is decided upon it is preferable to set the retorts in two vertical rows of four rather than in two rows of three and one row of two. In addition, the former arrangement gives a greater yield per square foot of ground area. The chief objection is that if hand charging is in vogue a platform will have to be used for the top tier.

(9) The vertical division walls supporting the retorts need not be of greater width than 4½ inches, provided that 9-inch walls are put in where the retort joint comes. The walls forming the combustion chamber should not be less than 6 inches in width.

(10) The gases should be throttled to a certain extent at the top of the setting. These get away too quickly if excessive room is permitted. The bottom retorts should be no more than 4 inches to 4½ inches from the side of the main arch wall.

Specifications for Horizontal Benches

It would not be possible, owing to the multitude of designs now adopted by individual engineers, to give here a general specification for a horizontal retort-bench. The foregoing pages should, however, prove of some assistance to the engineer contemplating extensions or renewals; and, with their aid, there should be little difficulty in compiling specifications for benches of whatever type or capacity. The chief points requiring consideration have been fully dealt with, and in addition it is imperative to ensure that first-class material should be used throughout. The joints should be thin, and two to one cement mortar used in all stock brickwork, with fireclay cement for all fireclay work. As regards the types of materials suitable for various portions of the setting, reference should be made to Chapter VI, dealing with Refractory Materials.

THE COST OF HORIZONTAL RETORT SETTINGS

Costs of erection will necessarily vary to some extent in accordance with the fluctuations in price of materials and labour, also the design or "stiffness" of the work put down. As an instance of the latter item it may be pointed out that stage floors, whilst costing on an average about £3 per mouthpiece, may rise to as much as £8, in cases where exceptionally heavy charging machinery, etc., is allowed for. Other factors affecting the ultimate cost are the distance and ease of access of the point of supply from the site on which the structure is to be erected, also the prevailing railway rates and water freightage. In most cases all the above considerations should not influence the following prices to a greater extent than 5 per cent. in either direction. Owing to competition amongst contractors, a certain amount of "cheeseparing" is inevitable in the preliminary tenders; for this reason the figures given below lean, if anything, towards extravagance—that is to say, they exemplify expenditure where a few extra pounds have not been withheld.

No. I

Settings of "Tens." Two vertical rows of 5 retorts, 24 inches × 16 inches × 20 feet. Say about 10 beds, carbonizing 130 tons per diem.

	£	s.	d.	
Foundations and excavation, for bench and chimney	2	0	0	per mouthpiece.
Arches, spandrils, main flue	9	0	0	„
Buckstays and steel bracing	2	10	0	„
Chimney: Brickwork, £1 7*s.* 6*d.*; bracing, 7*s.* 6*d.*	1	15	0	„
Mouthpieces, hydraulic mains, ascension pipes (both ends of retort), and all retort ironwork	14	0	0	„
Tar towers (C.I.) and fittings	0	15	0	„
Retort-house governor and connexions	0	10	0	„
Retort settings, producers, producer ironwork, etc.	20	0	0	„
	£50	10	0	per mouthpiece.

i.e. £80 per ton of coal per maximum diem.

Or £6 5*s.* per 1,000 cubic feet of gas per maximum diem.

	£	s.	d.	
Bench and fittings as above	50	10	0	per mouthpiece.
Retort house, including roof and foundations	33	0	0	,,
Stage floors: Steelwork, £3; concrete and expanded metal, £1 10s.	4	10	0	,,
Tunnel floors	2	0	0	,,
Stoking machinery (say "F-A" combined machine, coal conveyors, breakers, elevators, hoppers)	30	0	0	,,
Electric generating plant	5	10	0	,,
	£125	10	0	per mouthpiece.

£200 per ton of coal per maximum diem.

£12 17s. per 1,000 cubic feet per maximum diem.

N.B.—It should be explained that costs for horizontals based on the coal used are extremely erratic, and by manipulation of the charges and the use of more coal the above figure could be reduced from £200 to £160.

No. II

SETTINGS OF "EIGHTS," in three rows, 22 inches × 16 inches × 20 feet retorts. About 10 beds, carbonizing from 90 to 100 tons per diem.

	£	s.	d.	
Foundations and excavations for bench and chimney	2	0	0	per mouthpiece.
Arches, spandrils, main flue	10	0	0	,,
Buckstays and steel bracing	2	10	0	,,
Chimney: Brickwork, £1 10s.; bracing, 10s.	2	0	0	,,
Mouthpieces, hydraulic mains, ascension pipes (both ends of retorts), foul mains	14	10	0	,,
Tar towers and fittings	1	0	0	,,
Retort settings, producers, producer ironwork, etc.	21	10	0	,,
	£53	10	0	per mouthpiece

i.e. about £88 per ton of coal per maximum diem.

No. III

HORIZONTAL RETORT SETTINGS. Three beds of "Six"—22 inches × 16 inches × 10 feet. Carbonizing 10 to 12 tons of coal per diem.

	£	s.	d.	
Foundations and excavations	3	0	0	per mouthpiece.
Arches and spandrils	12	10	0	,,
Buckstays and steel bracing	3	0	0	,,
Chimney	2	10	0	,,
Mouthpieces, hydraulic mains, and all retort ironwork	13	0	0	,,
Retort settings, producer, and producer ironwork	21	0	0	,,
Tar tower and fittings, tar main, etc.	2	0	0	,,
	£57	0	0	per mouthpiece.

i.e. about £95 per ton of coal per diem.

INCLINED RETORT SETTINGS

Little attention need be given to inclined retorts, which cannot be considered as appertaining to modern gasworks' practice. The originator of the system, M. Coze, designed his settings with the retorts set at an angle of 32° with the horizontal —*i.e.* the theoretical angle of repose of coal. The chief merits (also largely theoreti-

cal) were the absence of charging and discharging machinery and the wear and tear connected with this apparatus, also only one ascension pipe was employed, this being at the lower end of the retort. Other experimenters have worked with the retorts at various angles ranging up to 45°; but it is now generally recognized that if automatic charging is to be carried out it is best done by placing the retort on end.

Inclined retorts are seldom entirely automatic, and the charge has invariably

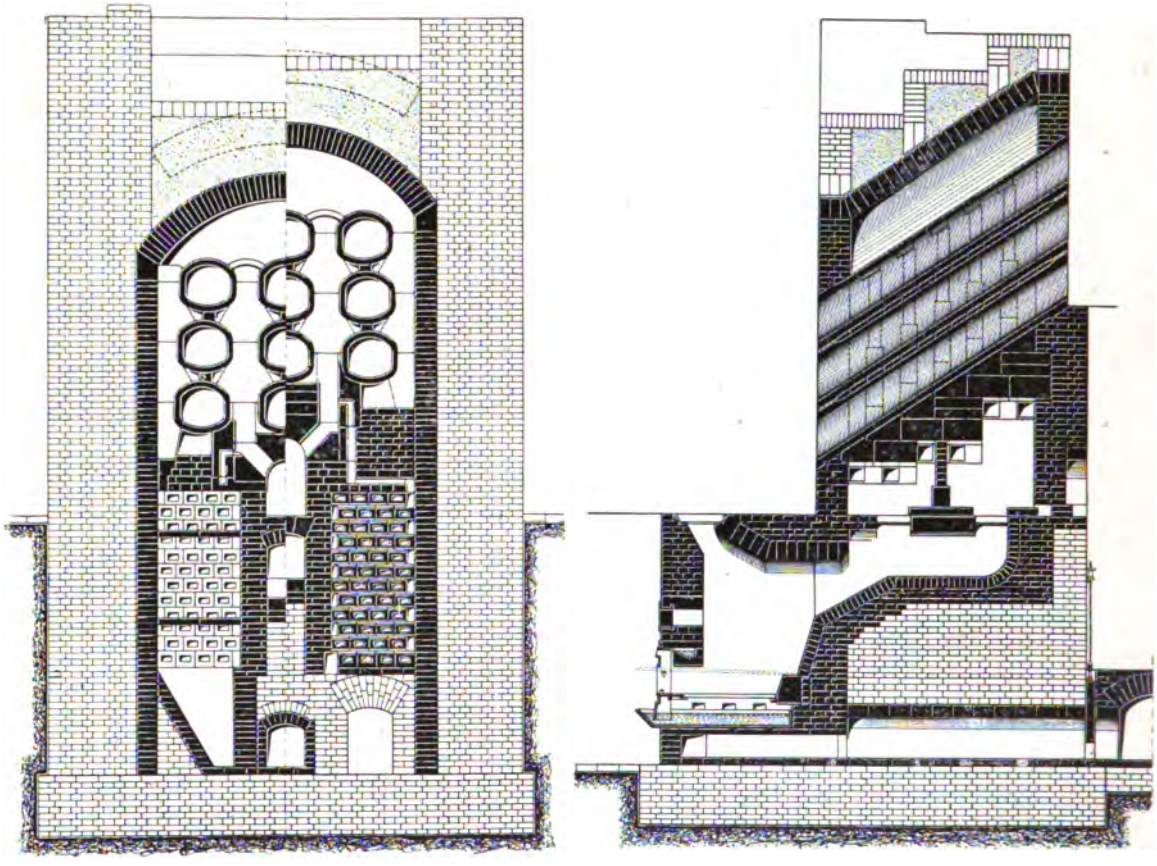


FIG. 45.—INCLINED RETORT SETTING.

to be "started on the run" by pricking up at the bottom and pushing from the top. Moreover, the character of the charge is materially affected by the kind, size and degree of dampness of the coal in use. "Creeping" often takes place during the period of distillation, with the result that the upper portions of the retort are completely uncovered. In G. R. Love's system the retorts were set at 45° and received full charges, two ascension pipes being provided. The system has now been abandoned.

With regard to fuel consumption, inclined systems are more extravagant than horizontals, and an average figure of 16 lb. of coke per 100 lb. of coal carbonized (*i.e.* 22 per cent. of the coke made) may be given.

The intricacy of this type of setting renders it more costly than the horizontal bench. For the complete setting, inclusive of all ironwork, producers, chimney, foundations, etc., the approximate cost per mouthpiece would be £65.

OUTSIDE PRODUCERS

The term " outside " or " external " producer embraces those types which do not form part and parcel of the retort bench ; that is to say, the producer gas is generated at some distance from the point at which it is to be consumed. Outside producers as now employed on gasworks may be classified as follows :—

1. Coke-fired. (*a*) External types. (*b*) Semi-external types.
2. Coal fired (or mixture of coke and coal), with plant for recovery of by-products.
3. High-pressure producers.

External producers of all types are entirely confined to the largest of gasworks. Although they cannot compete with the self-contained furnace on the score of fuel economy, their chief recommendations lie in a somewhat reduced capital outlay, if the producer is of a simple type, comparatively low labour charges, and little wear and tear. The working conditions for the men are also better. A distinct advantage, moreover, is the finer regulation of temperature in the settings owing to the possibility of passing the gas on its way to the settings through metal cocks. The ordinary coke-fired external producer is very similar in appearance and construction to a water-gas generator, the outer casing being made of mild steel plates, with a lining of firebricks and thin layer of slag wool. In all cases a forced air-blast is provided, consequently a comparatively fine fuel may be made use of. One of the largest installations of outside producers is that laid down at the Provan works of the Glasgow Corporation, some ten years ago. These producers, designed on the lines of that shown in Fig. 46, are rectangular (not circular) in section, and twelve of them were erected, to be used in conjunction with sixty beds each of twelve retorts. The steel casings are 13 feet 3 inches high by 9 feet 4 inches long and 6 feet 4 inches wide, and are lined with 9 inches of firebrick work, with a 2-inch cavity filled in with slag wool. The gas is led away from each producer by a lined flue casing measuring 2 feet by 3 feet 6 inches, this passing into a round main flue pipe of 4 feet 10 inches diameter. Owing to the forced draught made use of with this type of producer it is

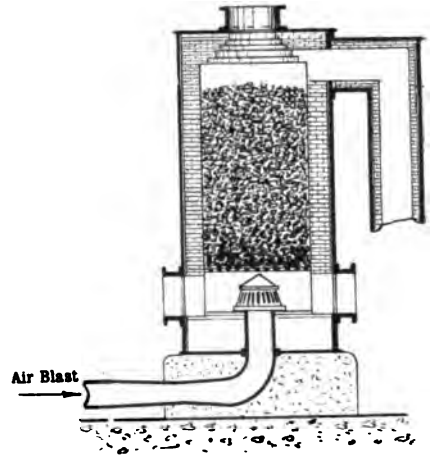


FIG. 46.—OUTSIDE PRODUCER.

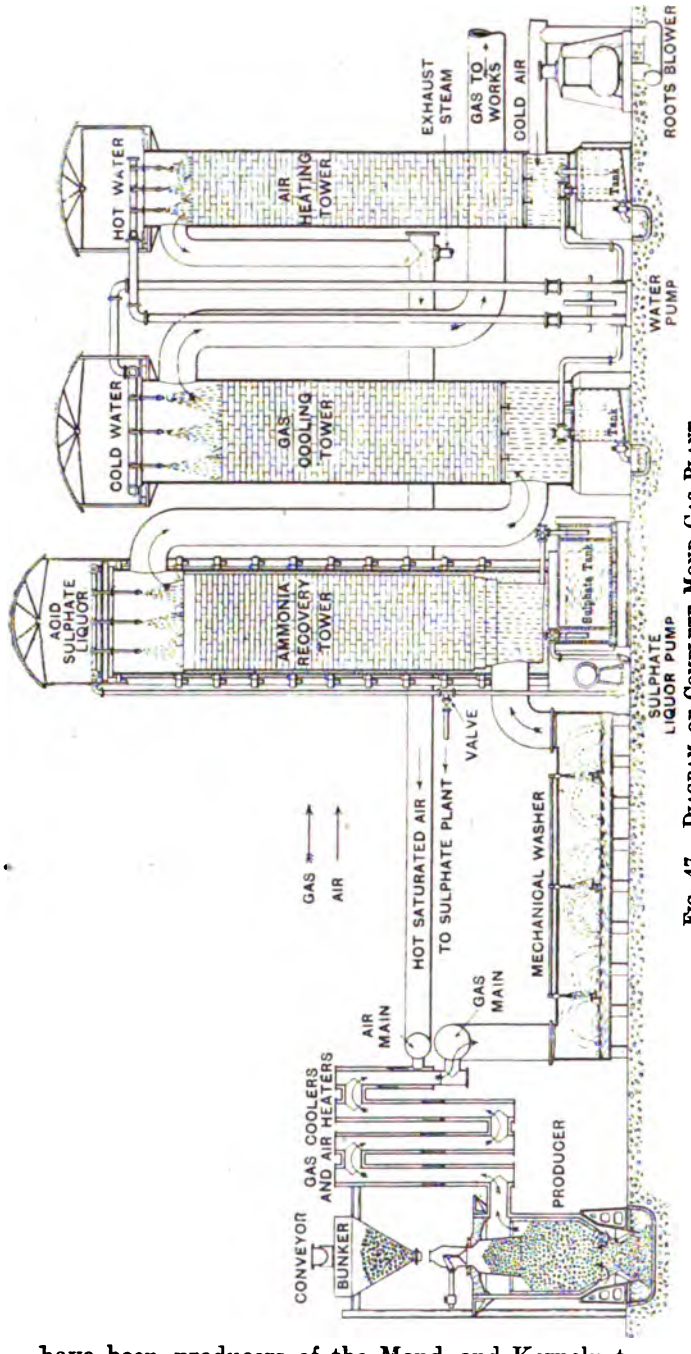


FIG. 47.—DIAGRAM OF COMPLETE MOND GAS PLANT.

essential that an efficient dust chamber should be provided, so that the gas is thoroughly cleansed before reaching the combustion chambers of the settings. In the Provan installation the main flue is intercepted by dust chambers measuring 22 feet high by 11 feet 4 inches long by 6 feet 10 inches wide.

The semi-external producers embrace those types which are adjacent to (and in some cases portion of) the setting, but which are of larger dimensions than the usual self-contained producer, and supply the requirements of two, or perhaps three, settings. In some instances these producers are erected on either side of the retort bench, and account for the heating of the half portion (on the side on which they are situated) of, say, three settings.

THE MOND PRODUCER.

Among the more recent introductions have been producers of the Mond and Kerpely types. The latter have, so far, been confined to Continental works. A Mond gas installation was erected

at the Saltley works of the Birmingham Corporation in 1912, for the purpose of heating a battery of coke ovens for the carbonization of coal. A general idea of the producer, complete with apparatus for the recovery of by-products, is shown in Fig. 47, whilst a section of the generator is given in Fig. 48. The producer may be fed with a mixture of coke or breeze and coal slack, and is capable of gasifying about 18 tons of these fuels per 24 hours. The Birmingham plant consists of five producers. The base of each is sealed in water, into which the ash descends, this being periodically removed without interfering with the process of gas-making. The producers can, if desired, be fitted with automatic ash-removing apparatus. A "wet" air-blast is blown through the fuel-bed by means of Roots' blowers, and in this way the temperature is maintained at a comparatively low point, so that ash alone, and no clinker, is formed. The quantity of steam introduced with the air-blast amounts to about 2½ tons for every ton of fuel gasified, when ammonia is recovered, the low temperature thus ensured preventing the splitting up of the ammonia, and accounting for nearly four times the yield obtained from the ordinary gasworks process of distillation. The supply of steam and air before entering the producer traverses a regenerator (in which it derives heat from the outflowing producer gas), and afterwards the annular space formed round the inner shell of the producer by the external casing. On leaving the producer and regenerator the gas passes to a mechanical washer, where, by means of a water spray formed by quickly rotating dashers, tar and dust are eliminated.

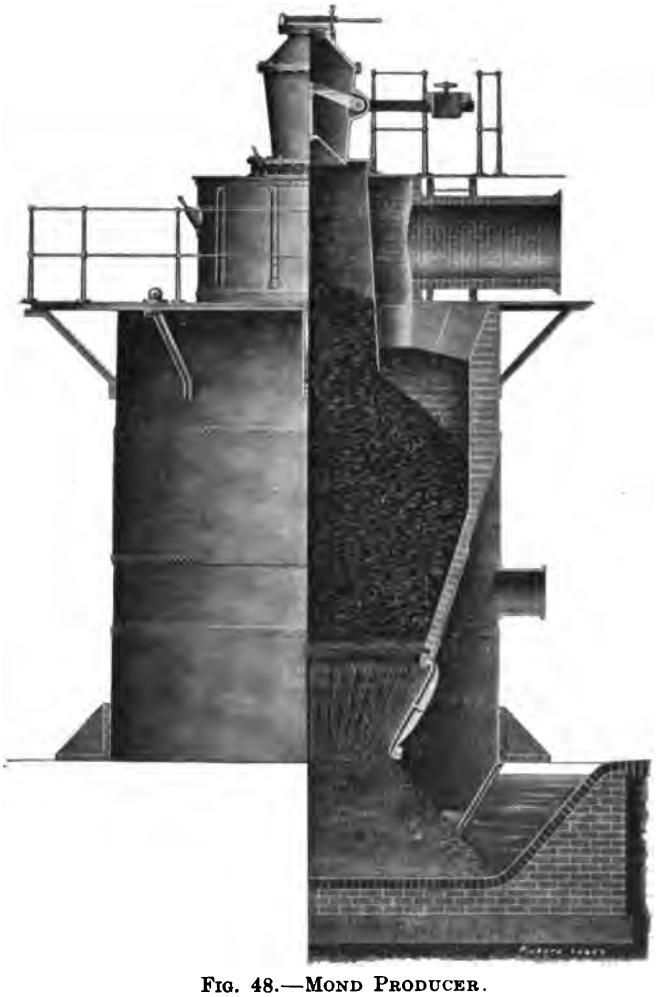


FIG. 48.—MOND PRODUCER.

Ammonia is then recovered by washing in a special tower with an acid solution, sulphate of ammonia being recovered direct, and the gas is finally treated in cooling towers and centrifugal fans for the removal of the last traces of tar.

In the case of large installations of Mond gas plants about 150,000 cubic feet of gas, costing ½*d.* per 1,000 cubic feet, can be obtained from a ton of coal slack. The calorific power of the gas is about 140 B.Th.U. per cubic foot. With regard to comparative costs of heating by Mond gas and by means of the ordinary coke-fired regenerator furnace, Mr. W. Chaney has given the following figures :—

COST OF HEATING RETORTS BY REGENERATOR FURNACES. BASED ON A FUEL CONSUMPTION OF 12 PER CENT. OF THE WEIGHT OF COAL CARBONIZED

Coke at 14*s.* per ton	20·2*d.* per ton of coal carbonized.
Labour	2·7*d.* „ „
Repairs and depreciation	1·0*d.* „ „
Total cost of heating	23·9*d.* (say 2*s.*) per ton carbonized.

COST OF HEATING BY MOND GAS

(*a*) All coal slack. (Compressed Coal in Chamber Ovens. *See* p. 182.)

Small coal at 10*s.* per ton	18·0*d.* per ton of coal carbonized.
Boiler fuel	2·15*d.* „ „
Labour	3·84*d.* „ „
Repairs and depreciation	8·53*d.* „ „
Oil, etc.	0·34*d.* „ „
Sulphuric acid, at 30*s.* per ton	1·95*d.* „ „
Sulphate bags, packing	0·46*d.* „ „
Gross cost	35·27*d.* per ton of coal carbonized.
Less sale of sulphate	18·81*d.* „ „
Net cost of heating	16·46*d.* per ton of coal carbonized.

(*b*) Mixture of half coal slack and half coke dust.

Small coal at 10*s.* per ton	9·0*d.* per ton of coal carbonized.
Coke dust at 1*s.* 6*d.* per ton	1·35*d.* „ „
Boiler fuel	2·15*d.* „ „
Labour	3·84*d.* „ „
Repairs and depreciation	8·53*d.* „ „
Oil, etc.	0·34*d.* „ „
Sulphuric acid, at 30*s.* per ton	1·30*d.* „ „
Sulphate bags, packing	0·30*d.* „ „
Gross cost	26·81*d.* per ton of coal carbonized.
Less sale of sulphate	12·52*d.* „ „
Net cost of heating	14·29*d.* per ton of coal carbonized.

THE KERPELY HIGH-PRESSURE PRODUCER

The Kerpely high-pressure producer (Fig. 49) is now at work in conjunction with retort settings or chamber ovens at many large Continental gasworks, including Vienna, Berlin, and Paris. The chief feature about its design is a revolving grate, by means of which the clinker as it is formed is ground up and thrown outside the producer. The producer is primarily employed on account of its ability to gasify extremely low-grade and dusty fuels — practically waste materials having a calorific power as low as 5,000 B.Th.U. per lb. As in the Mond system, air and steam are supplied to the producer, in this case up to a pressure of 30 inches of water. The lower portion of the shell is water-jacketed, which precludes the adhering of clinker to the side walls. In a recent trial run with pan coke having a calorific power of 10,500 B.Th.U. per lb., the gas produced was found of the following average composition :—

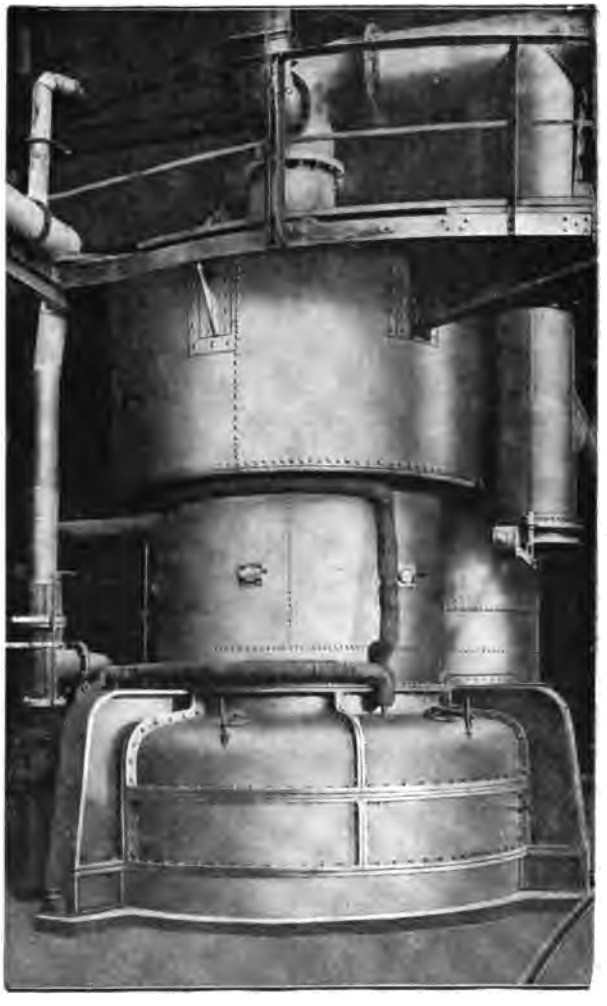


FIG. 49.—KERPELY HIGH-PRESSURE PRODUCER.

Carbon dioxide . . .	7·9 per cent.
Carbon monoxide . .	23·4 „
Hydrogen	12·5 „

The calorific power of the gas was 115 B.Th.U. per cubic foot. The high-pressure Kerpely producers are now made in two standard sizes, the larger apparatus being 8 feet 6 inches in diameter, 22 feet high over all, and having a fuel consumption of from 14 to 16 tons per twenty-four hours. Twenty-four of these producers are now at work on the Vienna gasworks.

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LOSS OF HEAT BY RADIATION

In connection with the loss of heat due to radiation from the conduits of outside producers, Butterfield has pointed out that if the producer stands at some distance from the setting, and the gas has to travel through long pipes before reaching the furnaces, or if it is stored for a short time in a gasholder, then 17 per cent. of the heating value of the fuel will be more or less completely lost. This amount of loss represents the heat which is expended in raising the producer gas to the temperature at which it leaves the furnace. With regard to the methods of insulation employed for maintaining the producer gas at the highest possible temperature, the author thinks that the researches of Neumann on the reaction between gases after contact with solid heated carbon have never been considered in conjunction with the working of outside producers of whatever type. Neumann has shown that at the furnace outlet there is a lower percentage of carbonic monoxide and a higher percentage of carbon dioxide in the gas than at the surface of the fuel, and that the total combustibles are less in percentage at the outlet than at a point just above the top of the fuel bed. It is further pointed out that the change in composition of the gas after leaving the fuel bed can be avoided by using an outlet pipe which is quickly cooled by means of a jacket through which cold water is circulated. From these researches it would appear, then, that the gas derived from producers of the outside type is extremely likely to deteriorate in quality to some extent during its passage along the comparatively long length of gas pipe ; and, what is more, the deterioration is likely to be augmented by the methods commonly adopted for the prevention of radiation. The question at issue, however, is as to whether the greatest heat economy would be entailed by cooling the gas immediately it leaves the producer, and thus checking the further oxidation of CO to CO_2, or whether the conservation of sensible heat due to the lagging, etc., is desirable even at the expense of an inferior quality of gas.

Outside producers, with the exception of the semi-external types, are always fed with cold coke, this accounting for additional thermal losses, unless the sensible heat in the coke as it leaves the retort is utilized (as in some vertical retort systems). When the cold coke is charged into the producer it should be as free from moisture as possible, otherwise this will be driven off in the form of steam, which passes on to the settings. In some forms of external producer the furnace gases are taken off at a point slightly below the average fuel level, so that any steam formed will be split up by passage through the hot coke.

CHAPTER IV

THE CONTROL OF HORIZONTAL RETORT SETTINGS

THE problem of the starting-up, working, and regulation of retort bench producers is one with which the gas engineer is continually face to face; and there are few more trying ordeals than that of warming-up to present-day heats, and afterwards maintaining such heats with regularity. First, it has to be realized that in the case of new work, or settings which have previously been in use, but have been let down, the range of temperature through which they have to be raised is as much as 2,000° Fahr., when considering the retorts, and about 600° higher as far as the combustion chamber and its immediate surroundings are concerned. Hence, if damage is to be avoided, more than ordinary care must be given to the procedure known as "slow fires." Rapid temperature rises are the sure forerunners of cracks and opening joints, whilst particular attention is essential with many of the modern forms of regenerators designed on elaborate lines for bringing about an interchange of heat between the waste gases and secondary air.

"SLOW FIRES"

With regard to picking-up benches from cold, there is a prevailing tendency to hurry the work along, which no doubt accounts in no inconsiderable way for the reduced life of retorts, etc., of which complaint is so frequently heard. The actual period of "slow fires" varies to some extent with the condition of the setting; that is, whether the brickwork is "green" throughout, or whether the bench has merely been let down for repairs. In the former case, an inflexible rule should be made that "slow fires" must continue for at least six weeks. This period may be reduced by half in the case of settings which have previously been under fire. At the end of this time the fire should be very gradually increased over a period of about three days to the full working pitch (*i.e.* "fast fires"), which must be continued for three or four days before the retorts are charged with coal. The procedure adopted for manipulating the various dampers and slides during preliminary heating and picking-up varies in accordance with the taste of the individual; but, speaking generally, the following points are those chiefly requiring attention in connection with the larger types of regenerator settings. First, with "slow fires" it is very usual to isolate the main flue and chimney during the earlier portions of the period, this being done by closing the main dampers between the regenerators and the flue. An outlet for the warm products of combustion is then made by removing a brick from the

front wall of the setting at a point just beneath the crown of the furnace arch. In this way the waste gases are circulating in the setting alone. In addition, of course, it must be remembered that the furnace charging hole is left uncovered. With regard to the admission of air to the furnace, most engineers prefer to open the primary slides only, keeping the secondary slots tightly sealed. This practice is certainly to be preferred, for then less risk of explosion is incurred; but at any rate the amount of primary air required will be trifling in comparison with that necessary for full work, and usually one-tenth of the quantity is ample for maintaining the fire at the desired pitch. During this time the fire-bars should be water-cooled in the usual way, and clinkering carried out about twice per week. As regards the retorts, the doors of these should be closed, so as to retain as much heat as possible; but they should on no account be tightened up with the levers, otherwise the expanded air and steam, being unable to escape (the foul-main valve being closed), will force an exit through some weak spot in the joints, thus giving unnecessary trouble when the retorts are charged up. Particular attention should be given to this point when new work throughout is being dealt with.

"FAST FIRES"

When the time comes for working up from "slow" to medium fires certain precautions are necessary. First, the main flue and chimney are brought into play; and to this end the setting dampers may be opened to a small extent (usually about one-quarter of their full working amount), but the outlet made in the front wall of the setting must at the same time be sealed by replacing the brick which was removed at the outset. In some instances it is usual to open the main dampers to nearly their full working extent for an hour or so, in order to heat up the shaft sufficiently to ensure its creating a good draught. From the point of view of the brickwork, however, this is not to be advised, and the better practice is to keep a coke bucket burning for some few days at the base of the chimney. A special brick panel or cast-iron door should always be left in the chimney for this purpose. When working medium fires the furnace lid is, of course, sealed up and secondary air admitted. The necessity for exercising a certain amount of vigilance before doing this is dealt with later. When the "fast fires" are commenced, the dampers and air slides may be adjusted to the maximum amount required for working the setting.

GENERAL WORKING POINTS

There is little doubt that the trained eye is by far the most effectual judge as to the manner in which the furnaces are doing their work. Systematic analyses are, no doubt, helpful so far as the prevention of waste is concerned, but their chief drawback is that whilst giving an indication of the quality of the producer gas they entirely neglect the equally important consideration of quantity. This accounts for the somewhat common experience of a scientifically perfect gas giving decidedly indifferent heats. As a preliminary, the most satisfactory method of adjusting the slides is to increase the primary supply until the best results are noticed, thus adopting a trial and effect policy. Having hit upon the correct adjustment, the secondary

slides are regulated until the characteristic blue flame of carbonic oxide is seen burning at the ports connecting the regenerators with the waste-gas flue. This indicates that the air entering through the inspection plug is burning the unconsumed CO. Such a state of affairs is, of course, wasteful, and the secondary ports must be further opened until the blue flame disappears. Sufficient quantities of oxygen for the combustion of the carbon monoxide are now entering the setting; but in order to ensure a slight excess the secondary slides should be further opened to a small extent, say about one-tenth of their amount at the time. In doing this, however, judgment must be exercised; for an additional quantity of secondary air means an increased volume of waste products, hence reduced combustion temperature.

WORKING UNDER PRESSURE

Within comparatively recent years the prevailing fashion was to work the retort bench under a slight vacuum throughout the whole of the setting. It is now recognized, however, that more effective results are ensured by maintaining a pressure in certain portions of the bed. If possible, an endeavour should be made to obtain a slight pressure in the combustion chamber, and this will depend to a large extent upon the position of the waste-gas damper. The latter should be opened to the least possible extent, and if adjustment must be made the primary slides should be turned to, when by further opening them matters will be improved, owing to the velocity of air through the fuel bed being reduced. All producers are, unfortunately, affected to no little extent by the varying conditions of the fire, such as clinkering, "pricking-up," fluctuation in depth of fuel bed, etc.; but the introduction of the automatic damper slide (such as Brooke's) has gone some way towards remedying this annoyance. The objects of such slides are:—

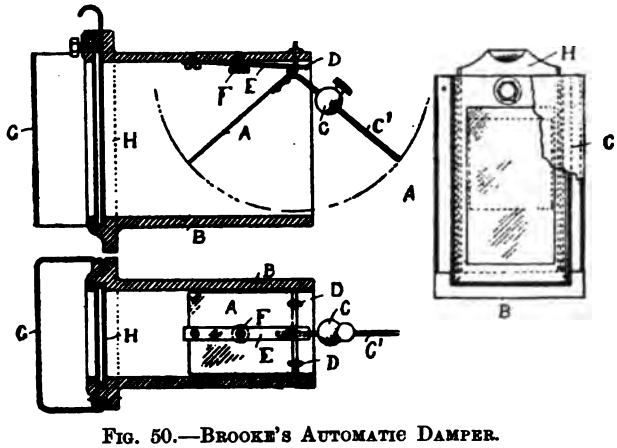


FIG. 50.—BROOKE'S AUTOMATIC DAMPER.

(*a*) To reduce fuel consumption.

(*b*) To maintain a more regular temperature in furnace and setting.

(*c*) To avoid excessive formation of clinker.

The apparatus (Fig. 50) consists of a vane A attached to a rod on which moves an adjustable balance weight C. The vane is supported from two small hook bolts on which it swings. A flat spring E presses on the spindle, the intensity of the pressure being regulated by the adjustable screw F. There is also provided a damper plate H for use when shutting down, and a shield piece G. The regulators are made

to fit into existing secondary-air flues, or to bolt on to the front of clinkering doors for the regulation of primary air. The fuel saving by the introduction of these slides has been shown in certain cases to be about 3 lbs. of coke per 100 lbs. of coal carbonized.

A similar type of regulator is also made for use with chimney shafts, which, owing to variations in atmospheric conditions, account for considerable fluctuations in draught. In this case the swing damper is balanced by means of a counterweight until it is just closed, when the desired draught is given. Any alteration of the main damper will then be accompanied by a movement of the regulator, which will open and admit cold air until the draught is reduced to the set amount. Variations due to atmospheric conditions will be similarly counteracted.

RELIABLE TESTS

A word is necessary here with regard to the manner in which tests on settings are made. When drawing off samples of waste gases it is advisable not to make use of the bottom or damper section of the regenerator for the purpose, as misleading analyses may be the outcome, owing to the by-passing of the secondary air. In many regenerator settings it is quite common to find that the vacuum in the secondary-air and waste-gas flues is practically equal, which is commendable as far as short-circuiting and by-passing are concerned. When such is the case, however, it rarely occurs to those responsible to analyze the ingoing secondary air at a section near the top of the regenerator.

A point worth noticing with regard to regenerators which show signs of serious short-circuiting is that of isolating the defective sections by transposing the air-box to a position higher up in the tiers of the regenerator. A certain amount of regeneration is, of course, sacrificed ; but usually the loss is more than balanced by the restriction of the short-circuiting. This alternative should only be turned to when repairs to the lower sections are impossible. Here, again, the engineer must be thoroughly conversant with the constructional details of his setting ; for, in more than one type of regenerator, the raising of the secondary-air inlet in this way would completely cut off the secondary supply to many of the nostril holes. In connection with these systems, the advantages accruing from the multiple regulation are undoubtedly significant, for there is frequently a tendency for the rush of air to be greatest towards the centre nostrils of the furnace arch. This entails irregular distribution of heat and dull mouthpieces. With the separate adjustments, however, the mouthpiece temperature is well under control.

As regards the regulation of waste-gas flue draught it is as well to provide two dampers to each regenerator, as shown in Fig. 51. The upper damper can then be regulated until the best results are given, while during temporary stops or clinkering the lower damper is brought into play. The latter can then be opened again to its fullest extent, and the draught is governed as originally by the upper damper, which has not been moved. Care must be taken, however, to see that the lower damper is properly sealed, otherwise air will be drawn past it, and the chimney draught on the setting correspondingly reduced.

It may be mentioned here that in the ordinary way the draught on the chimney of a regenerator setting should not exceed from $\frac{3}{10}$ to $\frac{6}{10}$ inch of water. The actual vacuum is usually measured by a special direct-reading instrument, the connecting pipe of which is thrust into the sight box at the base of the chimney. It is usual to calibrate these instruments in hundredth parts of an inch, so that for correct working the indicator points to between 30 and 60. Some engineers prefer to employ a recording gauge, so that a continuous record is taken.

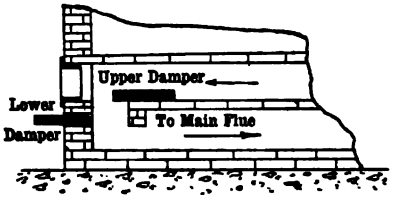


FIG. 51.—DOUBLE DAMPER CONTROL.

RETORT-BENCH EXPLOSIONS

Though serious damage resulting from the explosion of producer gas in retort settings is, fortunately, rarely met with on gasworks, it is, perhaps, surprising that this is the case, considering the singularly small amount of attention which is often given to the matter. The infrequency of these explosions is partly due to the fact that a large element of luck enters into the question, but chiefly because they are only likely to occur during the period when newly constructed settings are under "slow fires," or when benches are being picked up again for work. Mishaps of the kind, however, are particularly to be guarded against; for, in addition to endangering the limbs of those members of the retort-house staff who may be in the vicinity of the bench at the time, the resulting damage to the structural work of the setting may be considerable, entailing extensive rebuilding, and, consequently, expense.

It is somewhat puzzling to account definitely for the actual source of explosions of this nature, but in the greater number of instances it would seem probable that a mixture of carbon monoxide and oxygen finds its way into the setting at a time when the prevailing temperature is insufficient to bring about its ignition. What has to be recognized, of course, is that during the time when a setting is undergoing its preliminary heating up prior to being put into full work, the gaseous firing principle of the furnace is not brought into play, and the fuel is burnt merely as in the old type of "direct" fire. That is to say, a certain amount of primary air is admitted, the object being to burn the fuel to carbon dioxide in the furnace, and not in two steps, as is eventually to be done. If this could be ensured, then an incombustible gas would alone be circulating in the setting; but what usually takes place is that the primary air during its passage through the shallow bed of fuel is only partially converted into CO_2, whilst some CO is afterwards formed. At the same time air may pass through (particularly if the fuel bed is very uneven) entirely unchanged. Thus we have a mixture of CO and oxygen travelling throughout the setting. The general practice adopted during "slow fires" is to shut off the secondary air slides completely; but in some cases it is preferred to admit a small supply through these ports, for it is claimed that in this way a better draught is created, which ensures the more thorough removal of steam from new brickwork, etc. If secondary air is admitted,

however, it certainly adds to some extent to the possibilities of an explosion in the setting itself.

How Danger is Avoided

Explosions of producer gas, both minor and severe, are usually the outcome of carelessness on the part of the man responsible for the supervision of the settings, or are due to the non-observance of certain practical rules which have come to be recognized as the result of everyday experience. The most probable cause to which the trouble can usually be traced is that of sealing up the furnace charging door before the setting has reached a sufficient degree of heat. Some explanation of this possibility is, perhaps, necessary.

First, when the charging hole is uncovered any CO resulting from the combustion of the fuel, instead of travelling onwards through the nostrils and thence into the setting, will merely pass outwards into the retort house, where it will soon be carried away. If, however, the lid is replaced over the charging aperture, the combustible gas must necessarily find an outlet by travelling through the setting; thus the latter is filled with an explosive mixture. No harm may come of this for a time, but as the temperature of the setting rises the ignition point of the gas is reached, when explosion occurs. The magnitude and force of the explosion depend, of course, upon the volume of the combustible mixture which is circulating in the setting at the time.

Practical experience with the type of setting in question is really the most reliable guide as to when the state of affairs is safe for the furnace lid to be put in place. Usually it is merely sufficient to be satisfied that the furnace arch is just nicely red-hot, although more careful individuals go so far as to say that the bottom retorts should be at a dull red heat. The latter practice, however, is conducive to decided extravagance in fuel. But whichever method is adhered to, the chief object is to ensure that any carbon monoxide and oxygen which may be passing through the furnace will be ignited on arriving at the furnace arch, instead of finding its way into the setting.

Charging with Wet Coke

In addition to the charging-lid danger, other, but less hazardous, risks are run by filling up the furnace with decidedly wet coke, or by charging in an excessive quantity of cold coke at a time. In fact, the use of wet fuel should always be avoided; for, lying in a stagnant layer on the surface of the hotter fuel, it permits the passage through the bed of carbon monoxide and oxygen, whilst the actual flames are choked and subdued, and the temperature of the upper portions of the furnace is reduced for the time being. The result is that the inflammable gas is not burned in the furnace, and, circulating throughout the setting, it is eventually ignited when the heat of the fuel picks up, and the flames have broken through. Precisely the same argument applies to the use of cold coke, which, if used, should only be introduced in comparatively small quantities at a time. By far the best practice, however, is to use nothing but red-hot fuel from the nearest bench which happens to be in full work.

TEMPORARY STOPS

On the majority of the larger gasworks it is now quite the general practice to discontinue the make of gas for a certain period on Sundays; for by so doing the retort-house hands are assured of a well-earned weekly rest; whilst in many companies it is the custom to pay double rates between 6 a.m. and 6 p.m. on this day. Hence the temporary stop entails some fairly considerable saving in carbonizing expenditure.

As a general rule, the staff of a gasworks is not called upon to attend on Sunday, thus the operations of discontinuing carbonization and restarting it are practical problems with which many gas engineers are more or less unfamiliar. On first thoughts, the procedure would not appear to demand any exceptional amount of attention, and this is, perhaps, evidenced by the smooth way and unconcerned manner in which the works foremen carry out the duty week after week. The *modus operandi*, however, is by no means as simple as might be supposed, particularly as far as the maintenance of illuminating power is concerned, also the needless "blowing-off" and waste of moderately good gas. The responsibility is, of course, increased owing to the continuity of the process being broken, and the consequent difficulty in ensuring the candle-power being kept up to statutory requirements. In the case of the London companies, it will be remembered that after a good deal of controversy the London County Council proved their right to the Sunday testing of gas, some ten years ago. A glance through the tables of tests drawn up by the Council from their various stations shows, however, that the Sunday quality of the gas compares very favourably with that distributed during the week, and is seldom, if ever, inferior. In some cases vertical retort installations have somewhat modified matters, as has also the adoption of heavy charges in conjunction with the horizontal retort. Needless to say, the latter practice (that is, twelve-hour or ten-hour charges) has greatly facilitated the work of Sunday shutting-down.

Regulation of the Charges

No hard-and-fast rules can be laid down as to the line of action to be followed. Much must necessarily depend upon the conditions and facilities prevailing at the works—such as ample storage capacity, the type of retort settings to be dealt with, and whether enrichment by carburetted water gas or other means is available. The most general practice is to commence the non-gasmaking period at 6 a.m. and to continue it until 6 p.m., but in some instances, under favourable circumstances, a restart need not be made until 10 p.m.

It is proposed to describe here a method which will be found satisfactory from every point of view, and which has the primary advantage of being extremely simple. Though the method may be applied in all cases (whatever duration the stopping period may be) it will be assumed, for the sake of simplifying the illustration, that no retort-house work is desired between the hours of 6 a.m. and 6 p.m.

In this case the last row of retorts is charged so as to be completed by 6 a.m.; thus for some time the normal volume of gas is coming away. As this gradually decreases, however, no little precaution is necessary in the regulation of the exhauster

and retort-house governor. The method of operating these will be best followed by referring to the two charts shown in Figs. 52 and 53. In fact, the whole idea can readily be grasped by keeping these diagrams in mind. Fig. 52 is a vacuum chart showing the "pull" exerted by the exhauster throughout the twenty-four hours, whilst in Fig. 53 is shown the vacuum on the hydraulic main for the corresponding period.

Regulating the "Draw"

For the first hour and half, *i.e.*, until 7.30, the quantity of gas driven off will permit the use of the full average "draw." Following this period the volume of gas gradually becomes smaller and smaller, and the "draw" at the exhauster is reduced by degrees, until it is no more than half an inch about three hours after the retorts were charged, *i.e.*, about 9 a.m. Meanwhile, as will be seen from the second chart, the retort-house governor is adjusted so as to give "level gauge" on the hydraulic main; this continuing until 6 p.m. in the evening, when the retorts are charged-up once more. Similarly, the half-inch "draw" is maintained at the exhausters until shortly after 6 p.m., when it is raised gradually to the usual amount. When the exhauster is working at such a low vacuum as half an inch it must necessarily be running at its lowest possible speed, thus the "pull" is likely to be far from steady. In order to obviate this, and to put the engine under a greater load, it is advisable to slightly open the by-pass between the inlet and outlet pipes, this having the desired steadying effect.

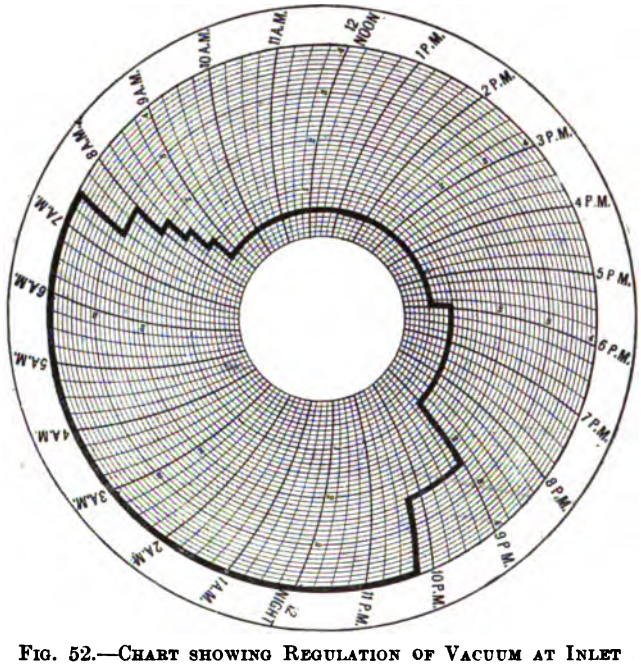


Fig. 52.—Chart showing Regulation of Vacuum at Inlet of Exhauster.

The advantage of working in this manner, as will be seen, is that there is no actual cessation of gasmaking, and the exhauster is at work during the whole twenty-four hours. In order that this may be the case, however, it is essential that heavy charges should be worked. If the old-fashioned light charges are in vogue, then gasmaking must inevitably cease, and a portion of the poor gas must be blown away as described below. With the heavy charges, the make of gas will, of course, diminish

by degrees, until, during the final hour before recharging, it will have dropped to about 7 to 10 per cent. of the normal figure.

Getting Rid of Inferior Gas

After the final charge of coal has been put in, it is the illuminating power of the gas evolved which really decides the manner in which the "draw" is to be regulated. It is a distinct advantage to have a special jet photometer run back from the outlet of the exhauster to the retort house, so that the foreman in charge has some indication of the quality of the gas soon after it has been generated. When the candle-power is noticed to be dropping, then the "draw" on the hydraulic main must be regulated accordingly. Unfortunately, in some cases, when an inferior coal is being used, the candle-power drops to such an extent that it is no longer advisable to send the gas forward to the holders. When this occurs, the continuity of the work has to be broken, and the exhauster is stopped while the poor gas is blown away. This is best done as follows: The main valve at the outlet of the condensers is closed and the exhauster driver (who is standing by waiting the signal) notices the movement of his chart. He then shuts off the steam on the exhauster engine, and immediately afterwards closes the by-pass, which was opened when the "draw" was originally reduced. Gas is still being evolved from the coal in the retorts, and an outlet must, of course, be provided for this, or some considerable pressure will be thrown upon the apparatus between the retorts and the condensers. This should preferably be arranged for by fitting a 4-inch pipe to the inlet of the condensers, the pipe dipping into a seal pot, and being sealed in liquor to a depth of about half an inch. The gas will at first bubble through the seal fairly freely; but as the quantity evolved gradually becomes less and less, precaution is necessary, for after a time no gas whatever will be evolved, and that already in the apparatus will cool and give rise to a vacuum. In consequence, air is liable to be sucked in through the blow-off seal. In order to prevent the possibility

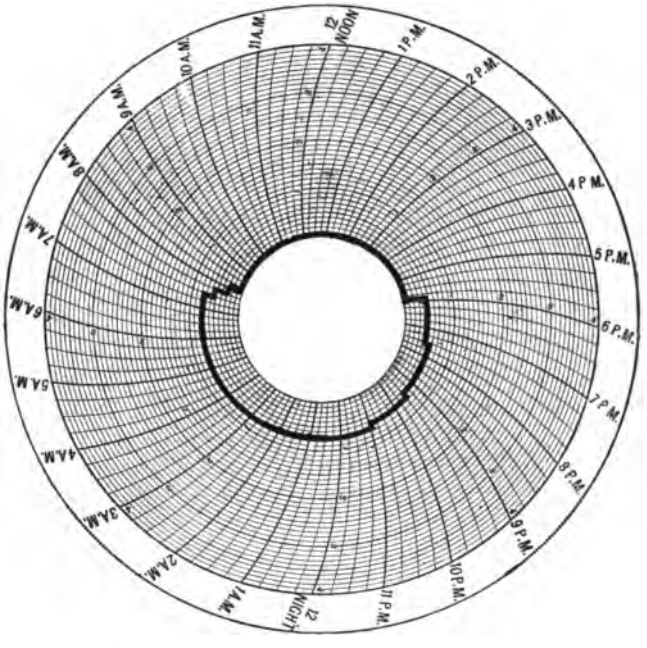


Fig. 53.—Chart showing Regulation of Vacuum by Retort-house Governor.

of this occurring, the seal on the blow-off pipe is deepened until a pressure of about 1 inch is thrown upon the apparatus.

The Prevention of a Vacuum

As serious results might follow any intake of air and the probable formation of an explosive mixture in the apparatus, it will be realized that the prevention of this vacuum is one of the outstanding points requiring special attention when temporary stops are made. Some engineers prefer the method of slacking-up the levers of the retort doors, so as to allow the surplus gas to find an outlet in this way. In the method described above, the lids are kept tightly sealed until the retorts are re-charged, and any gas which is expelled goes out into the open air and not directly into the retort house itself.

The late Mr. J. Tysoe drew particular attention to the liability of danger from the formation of this vacuum, and it is as well to recall his methods by quoting his remarks, which were as follows: "It frequently happens that sufficient gas is continuously driven off after the exhauster is stopped to maintain a slight pressure up to starting-time in the evening; but should the pressure entirely disappear before that time, sufficient gas may be admitted to restore it by means of a 2-inch by-pass at the inlet valve to the washers. On restarting the work, all that is necessary is, after a few retorts have been charged, to open the washer valve and close the safety seal at the condensers. By this method, all risk of explosion in hydraulic mains, of which many of us have probably had experience, is entirely obviated, perfect safety is secured, and very little good gas is lost."

It is interesting to note that previous to the above remarks, Mr. Tysoe had said that "Sunday stoppage means a loss, however it is carried out"; which reminds one of the fact that at this time (ten years ago) heavy charges had not been thought of. Now, of course, given a good coal, there is not the least necessity for any loss whatever.

Controlling the Heats

As retort charging is discontinued during the stopping period, it is quite unnecessary to keep the furnaces up to their full working pitch. The last charges put into each retort are allowed to "stew" during the whole twelve or eighteen hours, hence a considerable amount of heat may be dispensed with and fuel economized. Ideas differ somewhat considerably as to the most effective way of carrying this out, but the best and most economical results are, no doubt, obtained by merely using the main-flue damper to make the adjustment (this being closed down to about 75 per cent. of the normal amount); whilst, if preferred, the primary and secondary air slides may also be closed down by about half. The slides and dampers may then be opened again to their full working extent about 3 p.m., so as to be in readiness for the fresh coal charges at 6 p.m. If the dampers, etc., are regulated in this way the furnaces should easily outlast the whole period without requiring further charging with fuel. In fact, the latter is one of the features to aim at, in order to do away entirely with retort-house labour.

The Value of Water Gas

Perhaps one of the most serious objections to the Sunday stop is the possibility of sudden demands arising from such unlooked-for causes as fogs. However short the cessation of gasmaking may have been, it is always followed by some inroads into the gas available, and somewhat depleted stocks are the result. In some cases a works might conceivably find itself in an unenviable position should an abnormal demand arise after the retort-house hands had been dismissed for the day. It is under such circumstances that the value of a water-gas plant is felt; and, furthermore, should the quality of the coal gas have suffered owing to that evolved during the stop, a little further carburation will soon put matters right. Here the question of diffusion, and the value of the holders in this respect, plays some part. It may generally be taken for granted that should any inferior gas go forward to the holder, it will thoroughly intermix with better quality gas therein, with the result that the average quality is quite up to the normal. At times, however, there would appear to be some doubt as to whether complete diffusion does actually take place, and in holders in which the inlet and outlet pipe are side by side it seems possible that the gas (or certainly some portion of it) travels direct from one pipe to the other without any admixture with that already in the holder. The remedy for this is, of course, to avoid working both in and out of the same holder.

FUEL ECONOMY

It is merely necessary to turn to the prevailing figures of a decade or so ago to realize that fuel waste has been curtailed to an even more striking extent than the make of gas per ton has been augmented, so that, instead of having for disposal only about 55 per cent. of the coke made, to-day, with the modern type of producer, it is possible, with careful working, to put on to the market (including sales to other departments of the works) no less than 85 per cent. The true facts of the case are, perhaps, better exemplified by comparing the heat units expended with those obtained for such an outlay in the form of gas; for whereas about 80,000 B.Th.U. used to be necessary to yield 6,000,000 B.Th.U., we now require something less than 26,000 B.Th.U. to give a yield of over 7,000,000 B.Th.U. in the gaseous state. That is to say, a reduction of 66 per cent. in the B.Th.U. required has been accompanied by a rise of about 17 per cent. in the B.Th.U. obtained in the gas. Even now it must be remembered that the apparently effective furnaces of the present day have by no means approached perfection, and the amount of the total heat utilized is a notably small percentage of that contained in the original fuel. For the most efficient furnaces the loss in heat still amounts to about 45 per cent. of the total contained in the fuel. This figure was in the neighbourhood of 65 per cent. before the introduction of regeneration.

HEAT BALANCES

The question of the heat balance of a retort setting receives but meagre attention on the ordinary gasworks. Results can never be considered more than very

approximate, owing to the difficulties with which the investigator is faced and the assumptions necessary; hence the practical gas engineer finds no real use for them.

Of the total heat due to the combustion of fuel in non-regenerative retort settings the greatest individual portion is accounted for by that passing away with the waste gases—this amounting to nearly 50 per cent. of the whole. By the employment of regeneration, however, the loss from this source has been reduced by almost exactly one-half. The main sources of thermal losses in a setting may be briefly summarized as follows:—

(*a*) Carried away in waste gases.

(*b*) Carbonization of coal, and carried away by evolved gases and vapours.

(*c*) Radiation and convection from brickwork.

(*d*) Lost in ashes, clinker, etc.

(*e*) Decomposition of water in fuel and moisture in inflowing air. Also vaporization of water in ashpan and on firebars.

(*f*) Reduction of CO_2 to CO in producer.

The late Vivian B. Lewes has shown that if all the available heat of the fuel could be turned to useful account only 8·6 per cent. of the total weight of coke made would be required for carbonization. Among heat-balance investigators Euchêne has given figures which may be taken as best exemplifying the manner in which the heat is expended. For the ordinary setting in which regeneration is not carried out the following results are given:—

NON-REGENERATIVE SETTING.

Heat supplied—		
From coke		83·6 per cent.
From volatile products		16·4 „
		100·0 per cent.
Heat expended—		
		Per cent.
In setting 60·7 per cent.	Carried up chimney as gases, 34·7 per cent. Carried up chimney as water vapour, 12·5 per cent.	47·2
	Lost by radiation and convection	12·8
	Lost in ash and clinker	0·7
In retorts 39·3 per cent.	Used in distillation of coal	15·7
	Escaping by ascension pipe, in volatile constituents	10·4
	Escaping in hot coke	13·2
		100·0

The chief point to be noticed is that in this type of setting only 16 per cent. of the total heat supplied actually goes to fulfil the primary function of the setting—*i.e.*, the distillation and decomposition of the coal and its primary products.

REGENERATIVE SETTING.

Heat supplied—	
From coke	77·4 per cent.
From volatile products	22·6 „
	100·0 per cent.

Heat expended—

		Per cent.
In setting 45·9 per cent.	Carried up chimney as gases, 19·9 per cent. Carried up chimney as water vapour, 5·3 per cent.	25·2
	Lost by radiation and convection	19·9
	Lost in ash and clinker	0·8
In retorts 54·1 per cent.	Used in distillation of coal	21·4
	Escaping by ascension pipe, etc., in volatile constituents	13·8
	Escaping in hot coke	18·9
		100·0

The experiments of D. D. Barnum, of Worcester, Mass., in general corroborate the above figures, except in one important respect. Barnum obtained his figures for a bench in which regeneration was carried out entirely at the expense of the producer. The total loss accounted for by the chimney amounted to 47·6 per cent., and that utilized for distillation and decomposition to 21·6 per cent.

A comparison between Euchêne's figures and those of Barnum is given below. The former are converted from K.C.U. per 100 kilogrammes to B.Th.U. per 100 lb., so that both sets are expressed in similar units.

Regenerative Settings.

	Euchêne.	Barnum.
	B.Th.U. per 100 lb.	
Heat contained in fuel	180,547	215,623
Heat lost—		
In ashes	2,131	—
In flues	58,768	122,377
In volatile matter	32,398	23,333
By radiation	45,550	20,931
Heat in coke	44,253	33,708
Total heat expended	183,100	200,349
Absorbed during distillation	—	15,274
Dispersed during distillation	2,553	—

The chief point to be noticed is that whereas Euchêne finds heat to be liberated, Barnum's results indicate an absorption due to distillation. Undoubtedly both exothermic and endothermic reactions occur simultaneously during carbonization, and whilst more recent authorities agree as to the ultimate endothermicity of the process, its actual nature is still open to question. The most recent research in this direction has been carried out by Cobb and Hollings, who conclude that the exothermic reactions commence at 1,130° Fahr. and continue until

some high temperature is reached; but at 1,380° Fahr. endothermic reactions commence which mask the exothermic effect above that temperature. Moreover, whilst prolonged heating at 1,380° Fahr. does not effect a completion of the exothermic reactions, it would appear that it does complete the endothermic reactions, since after heating at 1,380° Fahr. there is some evidence of exothermic reactions up to 1,650° Fahr.

In the item "total heat supplied" in Euchêne's figures it should be mentioned that the percentage attributed to "volatile products" indicates the quantity of heat evolved in the retort owing to the supposed nature of the reactions; that is, it is the heat of the formation of the original coal, which is liberated by the process of carbonization. Mahler in his researches observed a loss of 3½ per cent. of the original heat units in coal due to carbonization, which he looked upon as representative of the heat liberated by the process. This figure, however, takes no account of "scurf" deposited in the retorts, or of naphthalene, for both of which some reduction must be made.

Further investigations have been conducted by H. Poole, who finds a balance, due to liberated heat, of 3·05 per cent.

Poole's balance of heat units is as follows:—

In original coal before distillation, 13,260 B.Th.U. per lb.
After distillation, B.Th.U. recovered—

In coke	8,296	B.Th.U.	
In tar	614	„	
In gas	3,418	„	
Lost in water, etc.	527	„	
	12,855	B.Th.U.	
Unaccounted for	405	„	or 3·05 per cent.
	13,260	B.Th.U.	

THE CURTAILMENT OF LOSSES

The economical operation of the modern regenerator depends, perhaps, more upon its structural features than upon any refinements in its working which may subsequently be introduced; for, more often than not, a producer is designed with but little thought to the many small yet telling items that count, with the result that, however much attention it may afterwards receive, it is never possible to economize beyond a moderate extent. The main point to be kept in view is the most effectual means for abstracting the maximum quantity of heat from the fuel—that is, the greatest possible proportion of its calorific value—and the utilization of this heat with the minimum of loss. On gasworks nowadays the fuels used, almost without exception, are coke and breeze; although with the price of coal slack at 3*s.* or so per ton lower than that of coke, the Mond producer may be a familiar feature of the large gasworks of the future. Tar as an agent for retort or boiler heating may be dismissed from serious notice, as the high price it is now commanding has rendered its use unprofitable, although it became quite popular as a fuel some years ago.

The price at that time, however, was 1*d.* (or less) per gallon; now it is nearly three times as much, and tar cannot compete with coke when costing more than 1½*d.* per gallon.

ITEMS FOR CONSIDERATION

Owing to the different methods of firing now employed on gasworks, that is, whether individual or "outside" producers, generators or regenerators, it is difficult to lay down hard-and-fast rules of construction and working applicable to all systems; but the principal heat losses liable to affect all types of producers may be summarized as follows:—

1. Incomplete combustion of carbon to CO.
2. Incomplete combustion of CO to CO_2.
3. Too rapid travel of primary air through fuel bed.
4. Too rapid travel of hot gases through setting, or too much chimney draught.
5. Losses due to fuel falling through firebars into ashpit or removed with clinker.
6. Radiation and convection losses.
7. Extensive variation in composition of producer gas.
8. Insufficiency of gas.

With regard to the first two items, these are, of course, avoidable, providing that no faults have been introduced in the design of the producer; and they are best remedied by systematic analysis of both the producer and waste gases. It is necessary, however, to emphasize the fact that satisfactory gas tests do not in any sense ensure good heats; for, although the combustibles may be present in ideal proportions, it is quite possible that they may not be present in sufficient quantities.

The third item in the list lends itself to adjustment, providing, again, that the construction of the producer is not to blame. If this is the case the trouble can usually be traced to an insufficiency of grate area, the importance of providing adequately for this having been somewhat underestimated by designers in the past. Slow travel of the primary air through the fuel bed is ensured with abundant grate area (*see* Chapter III, p. 63); whilst there will be less "slip" up the sides of the furnace, and a shallower bed of clinker will be formed. Owing to the extended contact of primary air and coke, the quality of the gas will be materially improved.

On no account should the velocity of draught be so great as to draw off the gases from the setting before they have been cooled down in the regenerators by at least 700° Fahr., and the base of the waste-gas channel should be almost devoid of colour. This question of draught may affect the formation of the producer gas in two ways. First, the rate of travel of air through the fuel bed may be sufficiently slow for the formation of carbon dioxide in the lower portions of the furnace, but the time of contact may not be sufficiently long for the reduction of this gas to carbonic oxide—hence an excessive proportion of incombustibles in the furnace gas may result. So far as the draught is concerned it is the chimney height and flue area which are of importance in this respect (*see* p. 64).

CLINKER AND ASH

A word is necessary here with regard to the troublesome formation of clinker with some types of furnace. When clinker difficulties set in, it is, perhaps, the natural inclination of the man charged with its removal to make disparaging reference to the coke supplied to the furnaces at the time. A coal with a heavy ash content must necessarily increase the amount of inert matter to be cleaned from the furnace; but the secret of long periods without clinkering known to users of vertical retorts is due to the nature of the non-combustible portions of the fuel after passing through the furnace. With a strong draught a large proportion of the ash in the fuel is fluxed, with the consequent formation of clinker; whilst with a slow draught the heat of the furnace is reduced, with the result that little fluxing takes place, and ash instead of clinker is the outcome. Clinker prevents the admission of air, so that local combustion in the fuel bed takes place. With ash, on the other hand, furnace cleaning is a small matter; and it is possible to find works in which clinkering of the fires is practically unknown. With the Munich chamber system of carbonization the operation is carried out once in three months, although "pricking-up" is resorted to once a day. The remedy for the excessive formation of clinker is simple, and can be directly traced to the introduction of large grate areas and slow travel of gas; also in some cases to the employment of special water-cooled grates.

MAXIMUM COMBUSTION TEMPERATURE

The evil of admitting excessive quantities of air should perhaps receive some mention here; and it must be borne in mind that the highest temperature which can be obtained by the combustion of fuel is that to which the products are raised on their formation by the heat dispersed. Thus, the larger the volume of gas to be heated the less will the temperature be. It is in this respect that regeneration tells; for when the air is heated before combustion is allowed to take place, the heat of the air is added to the heat of combustion. Thus the quantity of heat available for raising the temperature of the products is very much greater.

With regard to vertical retort furnaces and the economical lines on which they are operated, it may be pointed out that in the Glover-West type the secondary air is preheated by circulating around the coke chamber constituting the bottom three feet of the retort, and in this way the sensible heat is extracted and turned to useful account. In the Woodall-Duckham system the coke is discharged more or less cold, but in recent installations a new device has been made use of by means of which the primary air passes through fireclay tubes adjacent to the base of the retort, thus utilizing heat which was originally lost.

A warning is necessary here with regard to filling up furnaces with partly carbonized or "tacky" coke; that is, if the charges in the retorts are not burnt off, their discharging into the furnaces should be postponed. The effect of such sticky fuel is to restrict the primary air supply, by closing up the interstices between the particles of coke; and irregular combustion is the result. Furthermore, a certain amount of heat is absorbed in driving off the volatile constituents remaining in the coke, although these constituents may themselves be combustible.

SECONDARY AIR DIRECTION

In retort settings of nearly every design it is customary to find that the secondary-air channels are arranged round the furnace arch in such a manner that when the heated air emerges it meets the gases from the producer practically at right angles. Until recently the advisability of this method has never been questioned, but opinions now appear to be undergoing some change. Dr. Karl Bunte, in a recent paper read before the German Association at Strassburg, pointed out the shortcomings of this procedure, and stated that in all the more perfect of modern settings such conditions are obviated. The effect of introducing the secondary air in a strong current at right angles to the producer gases is to give rise to too thorough intermixing of the air and gases, with the result that short flames are produced. In order to ensure as uniform heating throughout the setting as possible such short flames should be avoided. To this end the gas and air streams should meet on almost parallel courses, in which case admixture of the two is gradual, and flames of larger volume are produced. The majority of existing settings can be readily adapted to meet this requirement. The method of dealing with a typical case is shown in Fig. 42. In this instance the secondary air is conducted in the ordinary way to the apex of the furnace arch by means of horseshoe channel blocks. As generally laid, the blocks provide for admixture taking place very nearly at right angles. A simple and effective means of providing for a more parallel flow is to split a 9-inch firebrick diagonally, and to insert it under the final blocks each side as shown, so that the latter are given an upward cant. The method will be clearly followed from the sketch.

It is interesting to recall here that the flame development takes place quite differently in vertical retort firing. In this case the flame follows a spiral course from below upwards (in the Glover-West and Dessau systems), or from above downwards (in the Woodall-Duckham system). The latter arrangement provides for the heating of the upper third of the retort by eight burners, whereas the lower portions of the charge are situated in a comparatively cool zone. In the Dessau furnace the regulation of the flame development is extremely well effected by means of brattices which ensure the gas streams taking parallel courses, whilst at suitable intervals mixing blocks are inserted which thoroughly churn up the inflowing air and gas.

CHAPTER V

VERTICAL RETORTS AND CHAMBER OVENS

THE present-day popularity of the vertical retort and chamber oven is, no doubt, the natural outcome of the growing preference for carbonization in bulk, and the tendency for the gas engineer to relieve himself as far as possible of the vagaries of manual labour. Although the evolution of the vertical retort in its modern form has taken place within the last decade, the idea is by no means a new one, for so long ago as 1828 Brunton patented an intermittent system having many features similar to those of the prevailing types of to-day.

The systems of vertical retorts at present in use may be divided into three distinct types.

(*a*) Continuous types.
(*b*) Intermittent types.
(*c*) Continuous-intermittent types.

Of these, the first-named system aims at solving the problem of ideal carbonization; that is, the continuous admission of relatively small charges of coal accompanied by the continuous extraction of that which has undergone distillation. Hence, undesirable variations in the quantity of gas evolved (inseparable from intermittent charging) are completely avoided. Intermittent types of vertical retorts embrace the principles employed in the horizontal bench, *i.e.* a definite charge of coal is arranged for at stated periods, the retort being emptied at the end of the distillation spell. Continuously operated retorts are never empty. Continuous-intermittent systems are those whose design permits of the retorts being operated on either the continuous or intermittent plan. So far they have not gained much headway in this country; but as they are of most recent origin, their wide adoption is scarcely to be looked for at present.

It is not proposed to discuss here forms of vertical retorts other than those which have been actually employed in this country and are at work at the present time. In addition to the systems enumerated below many others, originating from America and the Continent, are to be found. The systems in operation in the United Kingdom are:—

(*a*) Woodall-Duckham	Continuous.
(*b*) Glover-West	Continuous.
(*c*) Dessau	Intermittent.
(*d*) Elland system	Continuous or intermittent.

(*e*) Glasgow sytem . . . . . Continuous-intermittent.
(*f*) Herring's system . . . . . Continuous.
(*g*) Holmes-Winstanley . . . . . Continuous or intermittent.

Among the earlier systems was the Settle-Padfield, in which the retort commenced in a vertical plane, but turned off at an angle at the base, so that the coke was discharged through the side of the bench, and not at the bottom. Charging was arranged for on continuous lines, but the coke was withdrawn at definite intervals, so that the amount of free space in the retorts was subject to variation. The system has now been discarded.

It is difficult to draw comparisons between the continuous and intermittent systems. In most cases the engineer must take into consideration the prevailing conditions, and select his system accordingly. In comparison with horizontal systems the following advantages may be claimed for vertical retorts.

(1) Greater yield of gas on a given area. For horizontals the average yield is 200 to 250 cubic feet per square foot of ground area. For verticals this figure may be increased to as much as 475 feet per square foot of area—according to the system.

(2) Better conditions in retort house and no very arduous labour. Less clinkering.

(3) Low consumption of fuel (*see* p. 47). This claim, although invariably made for vertical systems of the continuous type, must be viewed with a certain amount of reserve. Such figures as have been given usually favour the vertical systems, but these are mostly the outcome of trial runs, and are not altogether borne out by extended practical working.

(4) Control of heats as regards various sections of the retort. In the modern horizontal setting the multiple control of secondary air ensures almost as perfect adjustment.

(5) Each particle of coal is subjected to exactly similar treatment. This means that all coal passes in turn through the various temperature zones prevailing in the retort, and there is no trouble with uncarbonized portions of coal, as is often the case near the mouthpieces of horizontal settings.

(6) With continuous systems the gas is certainly produced in more uniform quality.

(7) The heat in the coke is in most systems utilized, and not wasted as in horizontals.

(8) The gas is not subjected to degradation by long contact in a large free space. This claim requires some substantiating when made in comparison with horizontals working with completely full charges. It must be remembered that the gas evolved from the lower portions of the vertical charge has to travel to the outlet pipe partly through red-hot coke and partly against the sides of the retorts (*see* p. 284).

(9) "Make per ton" may in some cases be increased by steaming the base of the charge, when the coal is sufficiently good to allow of this.

(10) Heavy and complicated charging and discharging machinery is eliminated —thus wear and tear expenditure is reduced.

(11) Labour costs per ton of coal per diem are from one-half to one-third less than with horizontal retorts.

The claims of the horizontal bench may be set down as follows :—

(1) The coke in vertical retorts has occasionally a tendency to "jam" up. This particularly refers to the intermittent types.

(2) The retorts are more difficult to repair during operation, and as the continuous retort is only cleared at long intervals a leak may go undetected for some time.

(3) The capital cost per ton of coal per maximum day is in general higher for the vertical systems. Inclusive of complete bench and foundations, coal-handling plant, power-operating plant, coke-handling plant, but exclusive of retort house, a vertical installation (according to size) will cost from about £150–£200 per ton of coal. The cost for a horizontal plant would be £110–£140 per ton, and in isolated cases less than the lower limit given.

(4) In continuously operated types any breakdown in machinery usually entails greater inconvenience.

So far as the relative merits of the two systems of verticals are concerned the advocates of the continuous type lay claim to the following advantages over the intermittent :—

(1) No air pulled in, because doors of retort are always closed.

(2) Quality of gas always constant.

(3) Each piece of coal undergoes the same treatment.

As regards the merits of the intermittent systems the following points are drawn attention to :—

(1) There is no machinery to breakdown.

(2) The retorts are accessible at any time for repairs, etc.

(3) Wear and tear is less, as there are no continuously working parts.

(4) Retorts are said to last longer, as no abrasion takes place by continuous movement of the coke.

(5) Increased yield of gas per ton, by steaming.

THE WOODALL-DUCKHAM SYSTEM

This system, which, with the Glover-West, has made more headway than any other type in this country, has undergone considerable modification since its introduction in 1903. Continuous charging and discharging was then arranged for; the base of the retort was water-sealed, and the coke, after passing the extractor, was quenched in the seal and removed by means of a short length of conveyor. Five years later the present system of coke-extraction was introduced and the water-seal abolished. The amount of coal passing into the retort and the rate at which the charge descends are automatically governed by the speed of the coke extractor. The coal occupies from seven to eight hours in its passage through the retort, which is 25 feet in length and of rectangular tapered shape.

Breadth and width of retort . . .	Top, 3 feet 10½ inches by 8 inches.
Breadth and width of retort . . .	Bottom, 5 feet 3 inches by 18½ inches.

The walls of the retorts are formed of tongued and grooved bricks, panelled out at the back so that heat is readily conducted from the flues to the charge (Fig. 54).

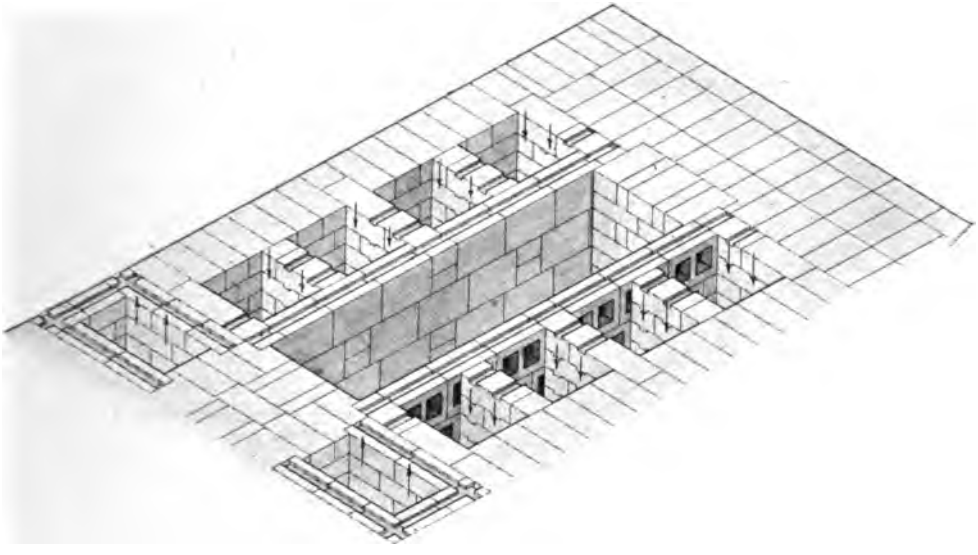


FIG. 54.—SECTION OF WOODALL-DUCKHAM VERTICAL SLOT RETORT, SHOWING METHOD OF BONDING SPECIAL BRICKS.

A point worthy of notice is that in this system, in contrast to the Glover-West, top-heating of the retorts is arranged for, *i.e.* the producer gas is admitted at the top of

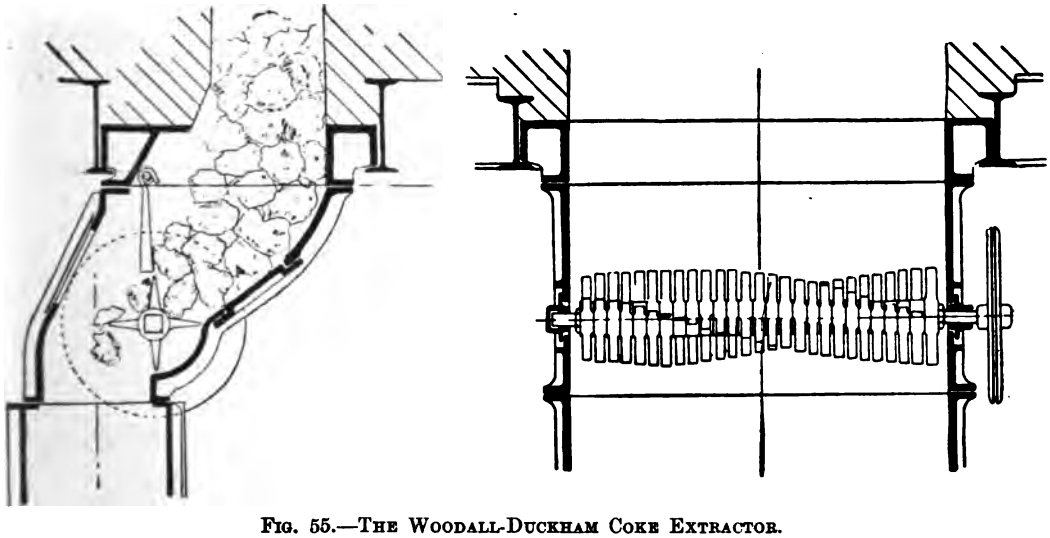


FIG. 55.—THE WOODALL-DUCKHAM COKE EXTRACTOR.

the vertical flues surrounding the retorts and travels downwards. The device employed for extracting the coke is shown in Fig. 55. The chief points to note in

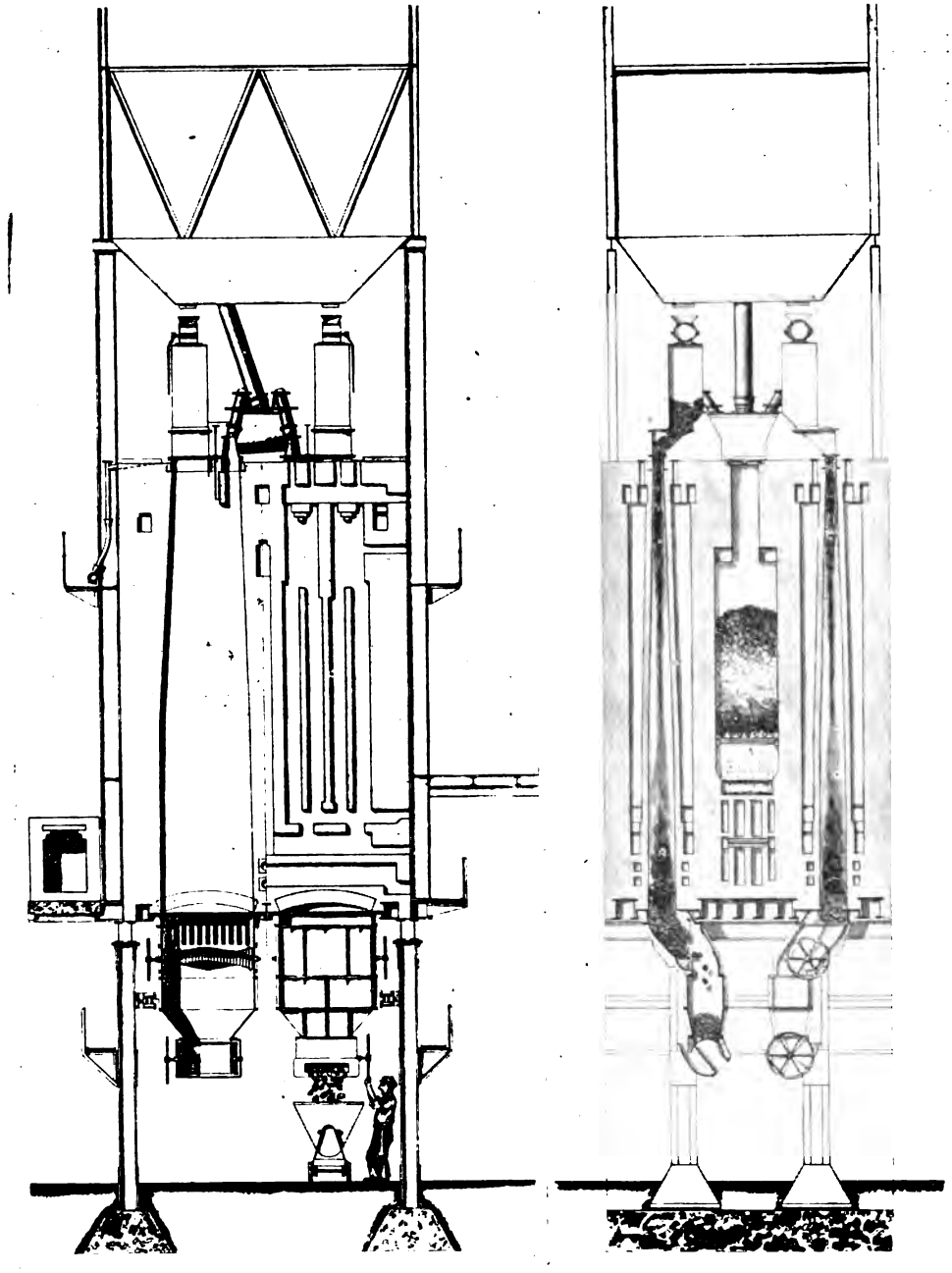


FIG. 56.—THE WOODALL-DUCKHAM CONTINUOUS RETORT SYSTEM.

its construction are that it is designed so that no shearing or cutting of the coke takes place, whilst it is relieved of the weight of the charge in the retort by curving the cast-iron extractor chamber. The speed of the extractor may be varied to suit the type of coal undergoing carbonization, but on an average it is one revolution in from fifty to seventy minutes. Driving takes place by means of a reciprocating bar continuous throughout the whole length of the bench. In the latest installations the rotary extractor has given way to an endless belt device. The coke after passing the extractor drops into a receiving hopper, which is emptied about every three hours. Quenching takes place, not by means of water, but by the circulation of the primary air around the base of the retort, so that the coke leaves the chamber, and is charged into the producer, in a cold state.

The coal-feeding device will be readily understood by reference to Fig. 56. It consists of a gas-tight hopper of mild steel plates mounted on a special casting

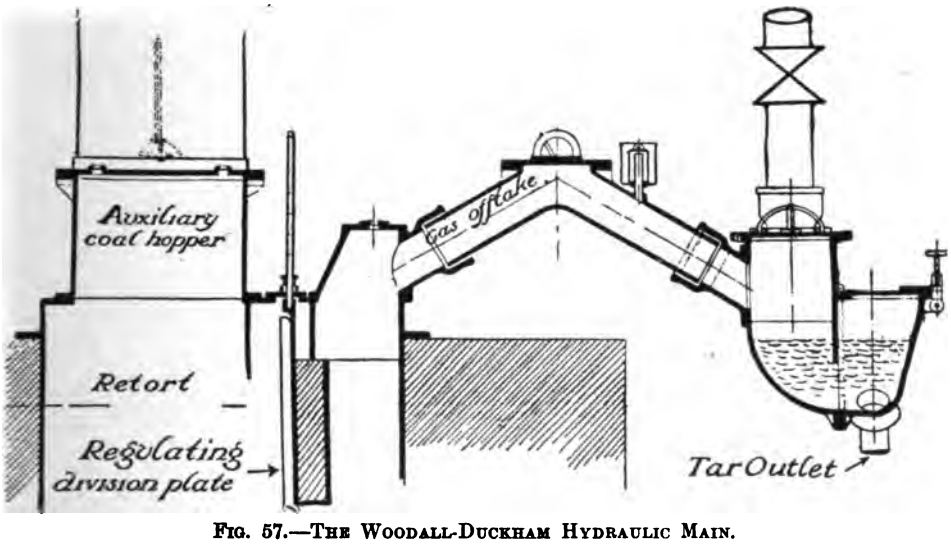


FIG. 57.—THE WOODALL-DUCKHAM HYDRAULIC MAIN.

attached to the retort mouthpiece. This hopper is closed at the top by a circular gas-tight valve, operated by hand about every three hours. The hopper requires about ten seconds to be filled. A special form of indicator shows the rate of flow of the coal into the retort.

In this system the gas is taken off by a hydraulic main (Fig. 57); and a unique feature is the provision of a regulating division plate so that the free space through which the gas must pass before leaving the retort is variable at will. The extent of this free space amounts to 0·7 to 1·4 per cent. of the total volume of the retort.

The following items are tabulated for reference :—

Coal carbonized per retort per max. diem	4½ to 5½ tons, according to class of coal in use.
Average yield per retort per max. diem	60,000 to 70,000 cubic feet.
Number of retorts in each setting	Four or two.
Grate area of producer	28 square feet per setting of four retorts.

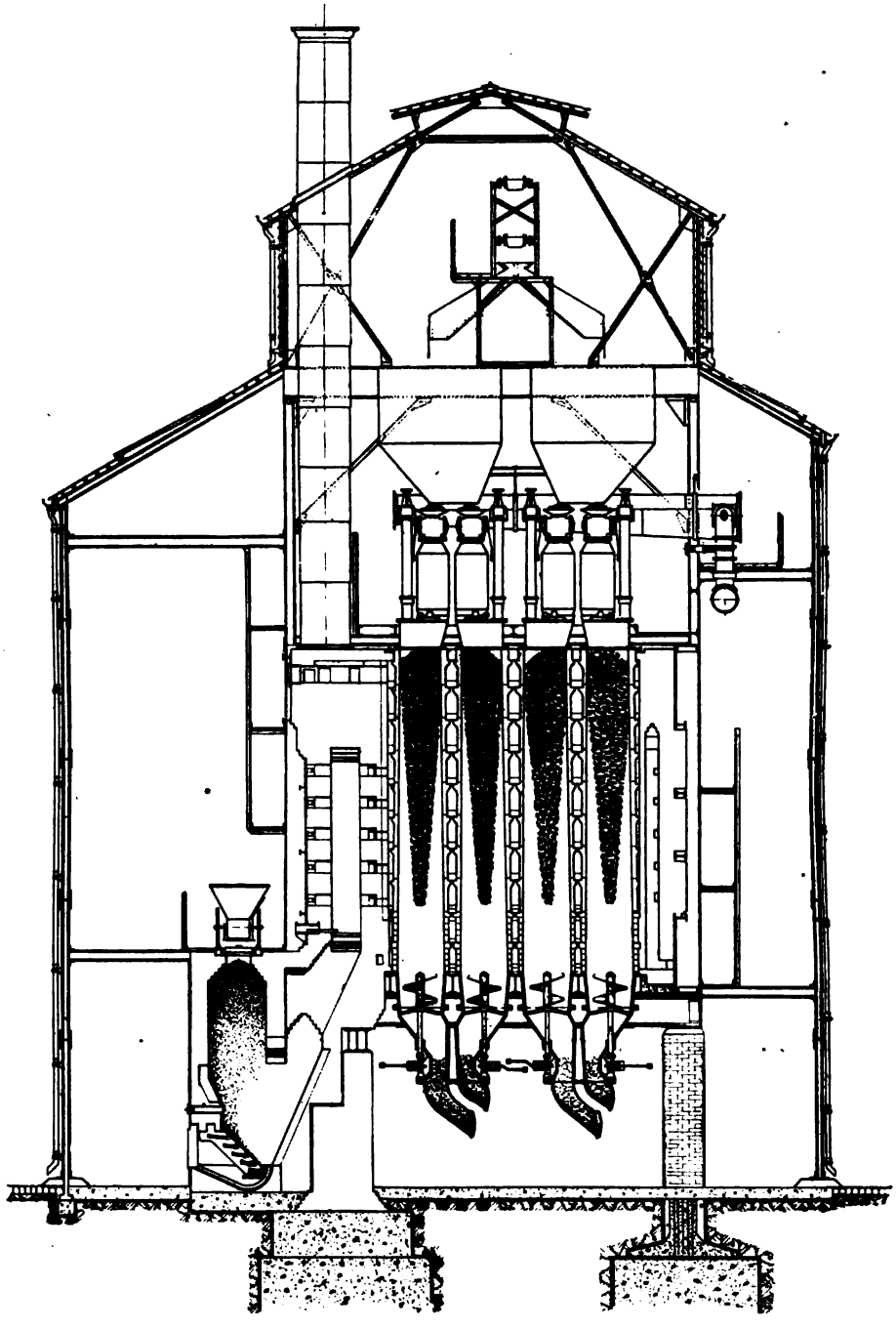


FIG. 58.—THE GLOVER-WEST VERTICAL RETORT SYSTEM.

Grate area per lineal foot of retort . . .	0·28 square foot.
Costs.—Complete bench, including foundations, coal-handling plant, and coke-handling plant, but exclusive of house.	£140–£180 per ton of coal per max. diem, according to size of plant.
Complete bench only, inclusive of foundations	£110–£155 per ton of coal per max. diem, according to size.
Cost of house, with foundations (per ton of coal per max. diem)	£25–£45, according to size of plant.
Power required per ton of coal per max. diem	1·8 b.h.p.
Power costs (minimum)—	
Coke extractor	½*d.* per ton of coal carbonized, at 1*d.* per unit for electricity.
Coke-handling plant	½*d.* „ „ „
Coal-handling plant	½*d.* „ „ „
Average period of clinkering producer. . .	48 hours.

It will be noticed that the grate area of the producer is considerably larger in proportion than that of the ordinary horizontal bench, this accounting for the longer periods for which the furnace will go without clinkering. At intervals of about six weeks the retorts are emptied and stood off for "scurfing."

THE GLOVER-WEST SYSTEM

This important system of vertical retorts was the outcome of patents taken out in 1905 by Young and Glover, founded in constructional details on the Scottish shale retorts. In 1909, the present Glover and West system was introduced. As in the Woodall-Duckham system, the ideal of continuous carbonization is aimed at, but the methods of arranging for this vary to some considerable extent in detail. First, the retorts are oval in section instead of rectangular, and are built up of concentric fireclay rings, whilst the bottom 3 feet of each is composed of cast-iron or special silica blocks, and forms a regeneration chamber for the secondary air entering the producer. The passage of the gas from the retorts will be readily understood from the figure, an

FIG. 59.—COKE CHAMBERS, GLOVER-WEST SYSTEM.

outlet being provided at the base of each coal-feeding hopper, whence the gas is conducted by a 7-inch pipe to a dry main. Each outlet pipe is fitted with a valve which is brought into use when a retort is out of action for scurfing purposes. Coke extraction is, of course, continuous, and governs the rate at which coal is delivered. The extractor consists of a slowly revolving vertical worm, driven by gas or electricity (about 3 h.p.) at a speed of one revolution in about thirty to forty minutes. The extractor is made in two halves, so that one half may be removed and the retort readily inspected. A novel feature enables the speed of the individual extractors to be regulated, so that if differing types of coal are in use in the retorts the speed of each worm can be adjusted to suit the particular class of coal. Dropping from the extractor the coke passes into a chamber fitted with a self-sealing lid (Fig. 59), and is removed from this at intervals of about two hours. The system of heating the retorts differs from that of Woodall and Duckham in that combustion takes place towards the bottom of the retorts and the waste gases pass around the upper portions into horizontal circulating chambers before finding their way to the chimney. On account of the cooling action of the secondary air passing around the base of the retort, no water-quenching is necessary, and the coke is discharged from the lower chambers practically cold. The producers are charged up with this cold coke at intervals of about four hours. The more important details of the system are summarized below :—

Shape of retorts	Oval.
Length of retorts	19 feet to 25 feet.
Breadth and width	At top, from 27 inches to 33 inches by from 12 inches to 8 inches; at base, from 36 inches to 39 inches by from 21 inches to 18 inches.
Number of retorts in each bed	Usually eight.
Coal carbonized per retort per max. diem	2½ to 3½ tons.
Average yield per retort per max. diem	30,000 to 37,000 cubic feet.
Grate area of producer	7 square feet per retort.
Costs.—Complete bench, including foundations, coal-handling plant, and coke-handling plant, but exclusive of house	About £150 per ton of coal per max. diem, according to size of plant.
Cost of house, with foundations (per ton of coal per max. diem)	About £30.
Power required	3 b.h.p. for extractor.

Strictly speaking, no clinkering is required with the latest form of producer fitted with stepped grate. Pricking-up and removal of ashes, however, is carried out every eight hours. The retorts are heated in a series of superimposed chambers and the heats can be varied at will. The chambers are divided into three : the top or waste-gas circulating chambers, the middle or heating chambers, and the bottom or regenerator chambers.

THE INTERMITTENT (DESSAU) SYSTEM

This system, which hails from the Continent, owes its inception to Dr. Bueb, who took out his first patent in 1902. In this, special apertures were introduced for

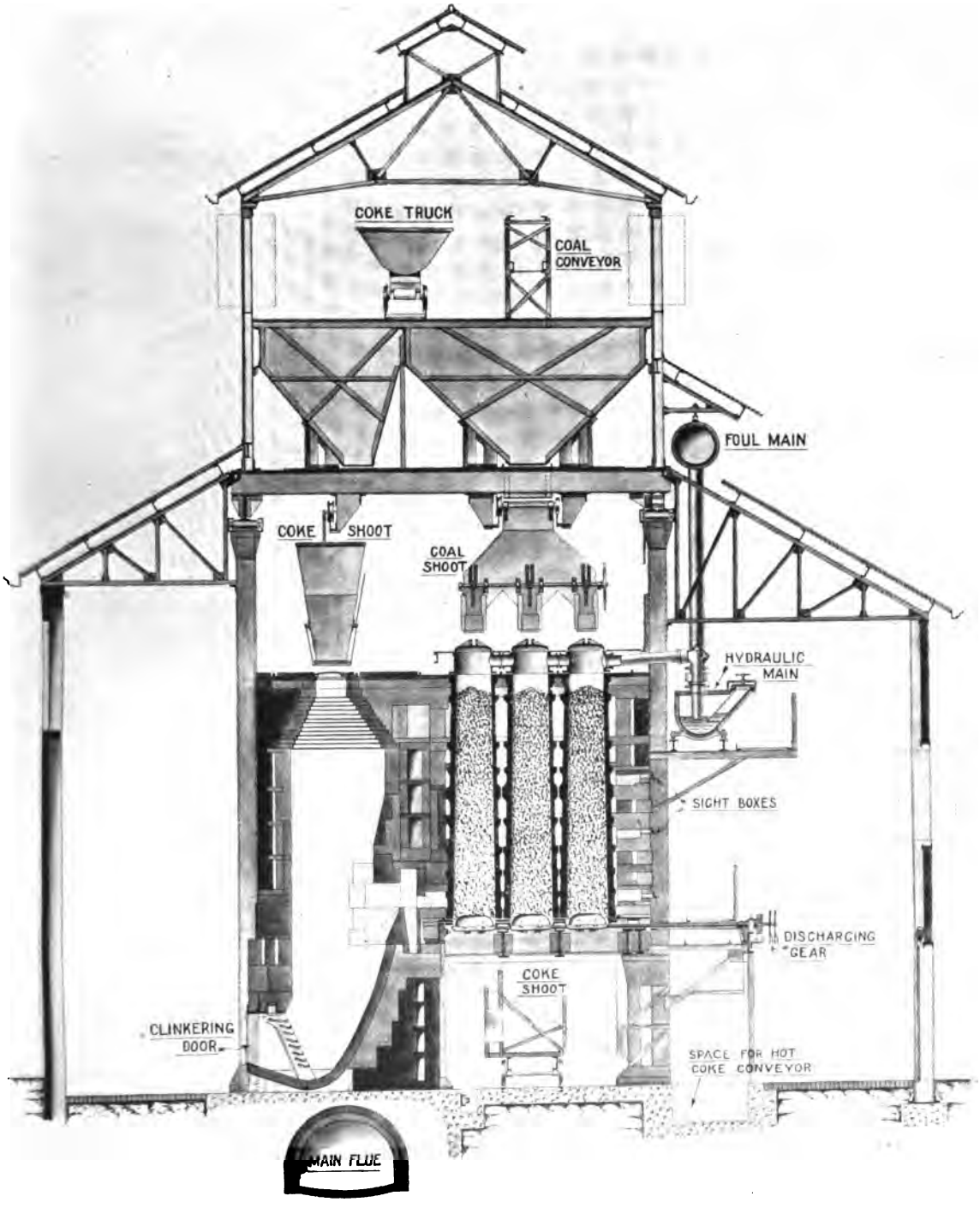


FIG. 60.—THE DESSAU INTERMITTENT VERTICAL RETORT SYSTEM.

taking off the gas from the side of the retort. Two years later these side outlets were dispensed with, and the system assumed the form, more or less, in which it exists to-day. In comparison with the two previously mentioned systems the chief points to notice are that as the retorts are intermittently charged no continuously operating machinery is necessary, whilst a ½-inch steam pipe is provided at the base for the purpose of steaming the charge and increasing the gas yield. The steaming, however,

FIG. 61.—SCALE MODEL OF INTERMITTENT SYSTEM.

is not continued throughout the whole period of carbonization; but with the usual 12-hour charge the supply is turned on for the last two hours. Self-sealing mouthpieces are provided at both top and bottom of the retort, and charging takes place from an overhead bunker by means of pouches drawn over the upper lids. An interesting feature of the arrangement of gas take-offs is that a common pipe is provided for each row of retorts, and the gas from the outer retorts passes through

the mouthpiece casting of those on the side nearest to the hydraulic main. A common spindle is employed for simultaneously opening or closing the lower lids, whilst a lever is provided for tightening-up the eccentric gear for ensuring effective sealing. As in the Glover-West system, the greatest intensity of heating is at the base of the retorts. The salient features of the system are tabulated below:—

Shape of retorts	Oblong with rounded corners.
Length of retorts	5 metres (16 feet 5 inches).
Dimensions at top	21 inches × 8½ inches.
Dimensions at base	27 inches × 14 inches.
Number of retorts set in each bed	4 to 18.
Coal carbonized per retort per 24 hours	22½ cwts. (12-hour charges).
Average yield of gas (with steaming) per retort per 24 hours	15,600 cubic feet (12-hour charge).
Grate area of producer	19 square feet.
Costs.—Complete bench, including foundations, coal-handling plant, coke-handling plant, etc., but exclusive of house	£150 per ton of coal per max. diem.
Cost of house, with foundations	£20 per ton of coal per max. diem.
Make per square foot of ground area employed (outside dimensions of retort house)	250 to 350 cubic feet.

Owing to the producer in this system being of the step-grate design, clinkering in the ordinary sense is only carried out about once in every three months, although the fires are pricked-up every twenty-four to forty-eight hours. The formation of hard masses of clinker is also checked by judiciously steaming the producer. To avoid loss of gas make from the imperfectly carbonized portion of the charge situated directly on top of the lower mouthpieces, a special shield is provided to keep the coal away from the door, and it is usual to run into the empty retort about 8 inches of breeze before admitting a fresh charge of coal.

THE ELLAND SYSTEM

Although one of the more recently introduced systems, more than half a dozen installations of the Elland type of verticals are now at work. The retorts are designed to work either continuously or with intermittent charges, to suit the requirements of the works.

The intermittent system (Fig. 62) differs from the continuously operated type in that the retorts are of considerably less total length. A special feature is the method employed for ensuring a partly porous charge so that the gases as they are evolved are provided with a ready exit. Unscreened coal is charged in a thin stream against one side of the retort, this causing the nuts to accumulate on the one side and the slack along that side at which charging takes place. In addition to ensuring a porous charge it is claimed that a less dense coke is produced; whilst the coal is permitted to shrink freely from the walls of the retort, and in this way facilitates discharge. On charging, the flow of coal from the hopper ceases automatically when the required level is reached. The shoot is then withdrawn, and its contents drop into the retort. The self-sealing lids are of special construction, a toggle system of levers being used instead of eccentrics; and a single pull by the attendant suffices

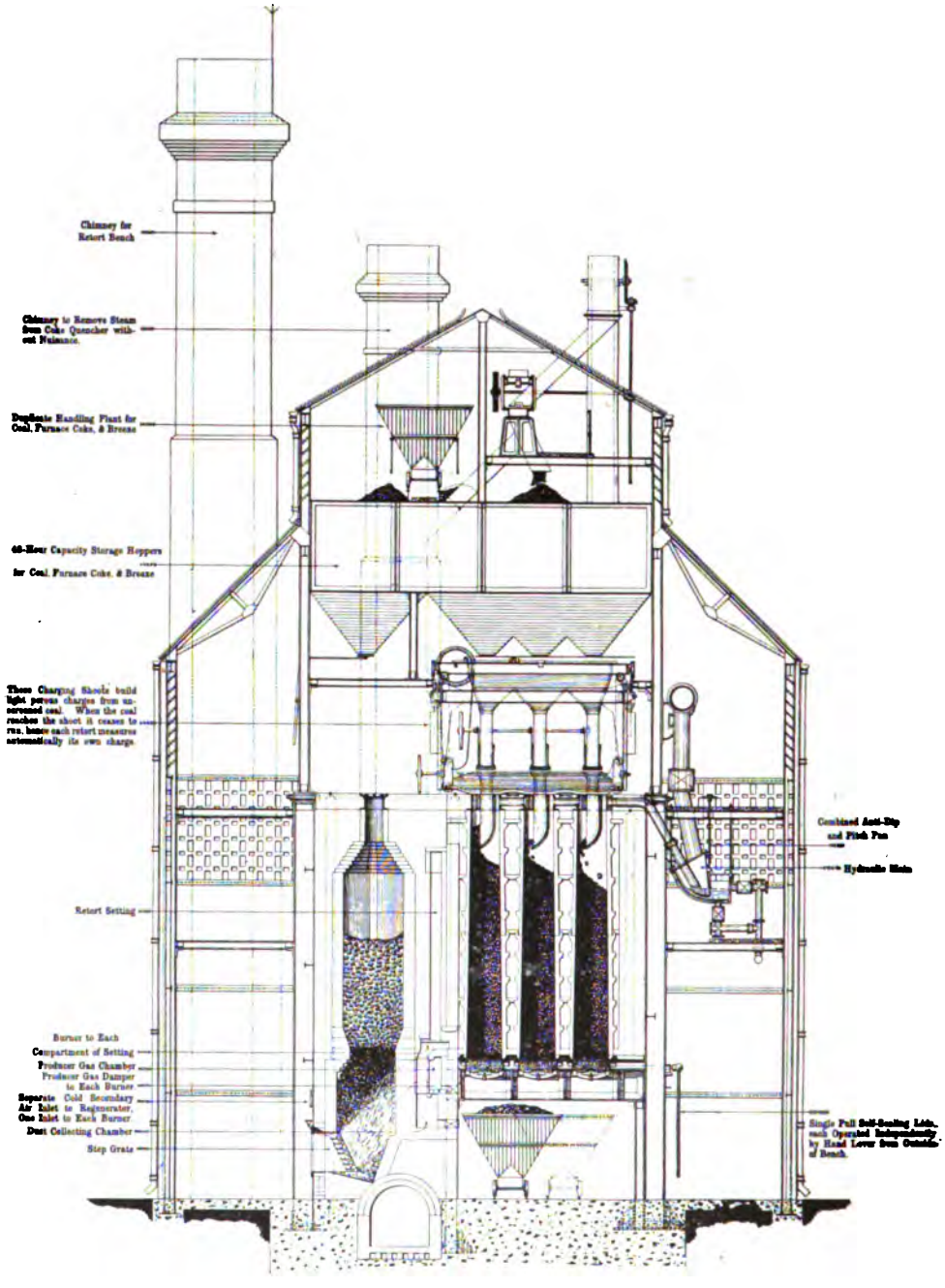

Chimney for Retort Bench
Chimney to Remove Steam from Coke Quencher without Nuisance.
Duplicate Handling Plant for Coal, Furnace Coke, & Breeze
48-Hour Capacity Storage Hoppers for Coal, Furnace Coke, & Breeze
Retort Setting
Burner to Each Compartment of Setting
Producer Gas Chamber
Producer Gas Damper to Each Burner
Separate Cold Secondary Air Inlet to Regenerator, One Inlet to Each Burner
Dust Collecting Chamber
Step Grate
Hydraulic Main

FIG. 62.—THE ELLAND SYSTEM OF INTERMITTENT VERTICAL RETORTS.

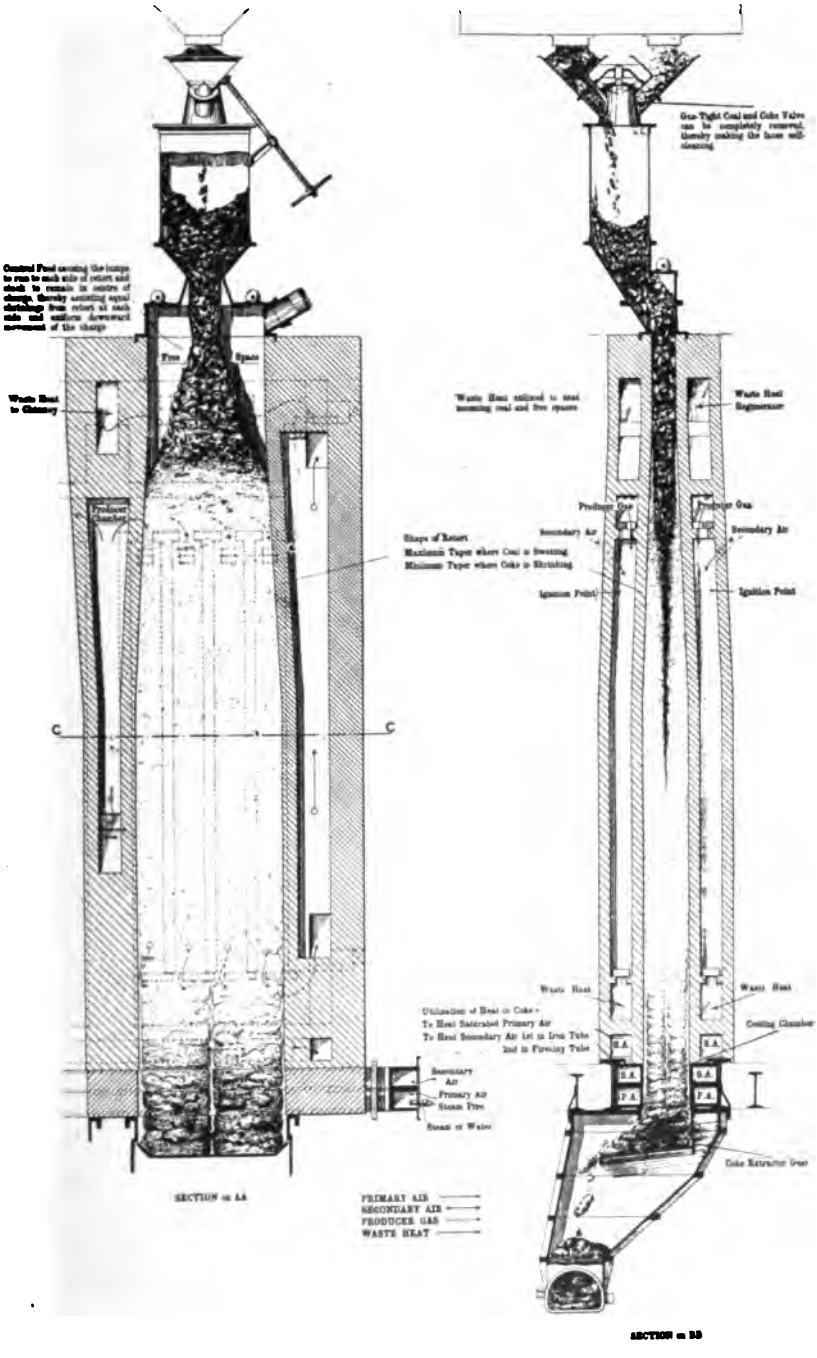
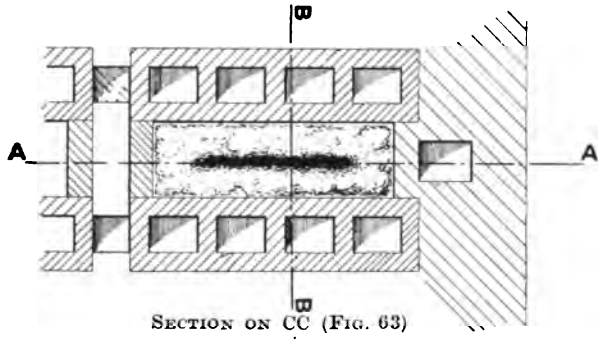


FIG. 63.—THE ELLAND SYSTEM OF CONTINUOUS VERTICAL RETORTS.

to raise and seal the lids. The regenerators are of the tubular type, and the setting is subdivided in a manner to give a maximum control of the heats. The retorts are usually set fifteen to a bed, are 16 feet 6 inches long, and each carbonizes 25 cwts. of coal per diem.

The Continuous System

The retorts in this system are 25 feet in length, and are charged by means of a gas-tight valve arranged with two inlets. One of these inlets is for the ordinary purpose of charging in coal, the other is for use in the case of those retorts which have undergone scurfing, and which first receive a charge of coke. As will be seen from Fig. 63, the coal is fed on the centre line of the retort. The taper of the retort is greater at the top than at the bottom; this is to accommodate for expansion of the coal on first heating. There are no stationary inclines or curved parts to support the charge, which during its downward travel meets successively larger cross-sections, until the extractor gear is reached. This actually supports the maximum cross-section of the charge, hence bridging or hanging-up is prevented. At the base of the retort is an inclined plate supporting the whole charge at the natural angle of repose, and the coke is gradually pushed off by the reciprocating motion of the plate, which makes one complete stroke in about seven minutes. The coke is cooled by circulating primary and secondary air around the base of the retorts, which are heated on their broad sides only. Each retort is provided with independent secondary-air supply, producer-gas and waste-gas dampers; so that individual control of heats is ensured. The retorts are built up from special moulded blocks, and each is rated to carbonize 5 tons of coal per day, four retorts being laid in each bed. The continuous retorts are approximately 5 feet wide by 18 inches broad at the bottom, this being reduced to 4 feet by 10 inches at the top.



Section on CC (Fig. 63)

Fig. 63A.

THE GLASGOW SYSTEM

This system, designed by Mr. Alexander Wilson, was introduced for the purpose of dealing with the non-caking or semi-caking Scotch coals, which under ordinary circumstances give a particularly small and friable coke. So far the installations have been chiefly confined to Scotland, and plants are at present at work at Glasgow (5 million cubic feet per day), Johnstone, Alloa, and Arbroath. In order that the charge may have ample time to consolidate, the coke is not drawn out continuously, but at intervals of about four hours. In this way a fairly large coke

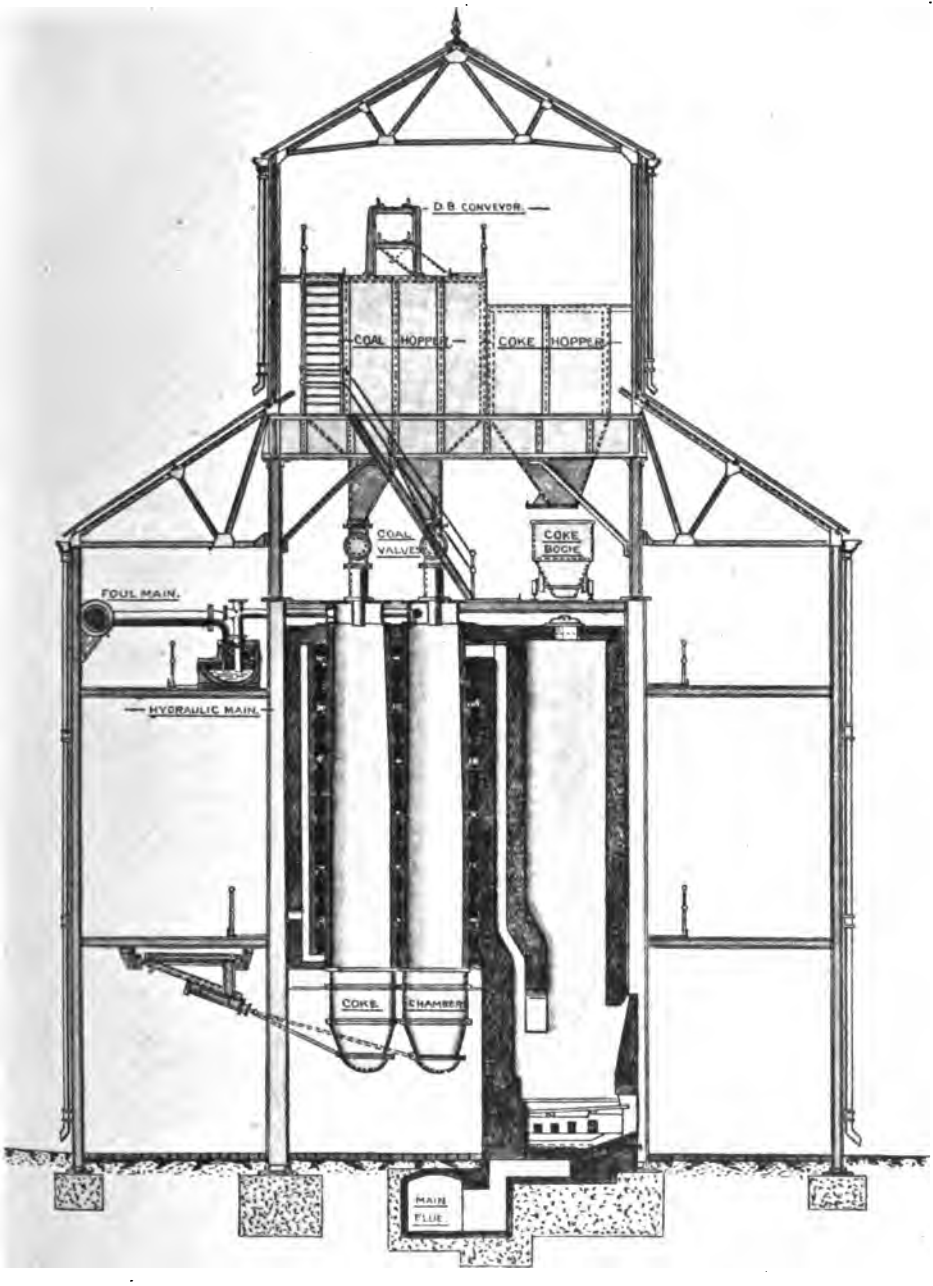


FIG. 64.—THE GLASGOW VERTICAL RETORT SYSTEM.

of good appearance is obtained. The quantity of coke extracted at each period of discharging is governed by the size of the wagon or shoot into which it is delivered; this is due to the fact that as the receiving wagon fills up it supports the whole weight of the charge in the retort, the bottom mouthpiece when being closed cutting through the coke column and sealing the base of the retort. No constantly moving machinery is required, and the coke is cooled in the bottom cast-iron chambers, to which are attached movable buckets for holding the water seals. These buckets are actuated by a small hydraulic ram, so that the movement of the handle of the water cock serves to push back the bucket, allowing the requisite quantity of coke to fall into the receiving wagon. Another movement of the handle then closes the bucket, which is sealed in water to render it gastight. The retorts, which are rectangular in section, are built up of tongued and grooved bricks, and vary in length according to the size of the installation. They are built with the whole of the taper at the top third of the length, the bottom two-thirds being parallel. For this construction it is claimed that unless the deposit of "scurf" is allowed to get very heavy there is no trouble with the holding-up of the charge when the retorts are drawn. The charging of the coal into the retort is effected by opening a large cock or valve having an upright plug, the lower opening of which connects with the retort and the upper opening with the coal hopper. The amount of free space in the retort (usually about 3 per cent. of the total volume) is regulated by a rod which projects into the top of the retort for the required distance. The movement of this rod indicates when the proper quantity of coal has been delivered, and the charging cock is then closed. For the benefit of the quality of the coke the coal charge may, if desired, be subjected to a small amount of steaming. The producers, which are fed with cold coke, are carried right up to the top of the setting, this giving an ample reserve of fuel, and thereby minimizing the amount of attention required. The producer gas is admitted around the upper portions of the retort, so that the maximum heat is concentrated here; the gases then circulate downwards, leaving the setting at the base. The coal hoppers are of large capacity in order to allow for sufficient storage to carry the work over Sundays without refilling. The following are the more important features in connexion with the design of the system :—

Retorts: Length		20 or 23 feet.
Breadth and width.	At top	40 inches by 10 inches.
	At base	48 inches by 18 inches.
Coal carbonized per retort per 24 hours		3 tons.
Average yield per retort per diem		31,500 to 37,500 cubic feet, according to class of coal.
Number of retorts in each setting		4, 6, or 10.
Grate area of producer		4 square feet per retort per bed.
Approximate time taken by coal in travelling from entrance into and exit from retort		18 hours.

HERRING'S SYSTEM

Mr. W. R. Herring's system of vertical retorts, erected at Edinburgh, differs from the majority of installations at work in this country in that the retorts are fired by

means of outside producers. The system may be worked on either the continuous or intermittent principle. When working continuously the coke extractor is devised to act as a cutter, wherewith the size of the coke is reduced as required. The retorts, which are built up of tongued and grooved bricks, are of rectangular shape, and receive their coal charge through a special closure apparatus (Fig. 65) which is designed to maintain a gastight joint while permitting the passage of the coal. The

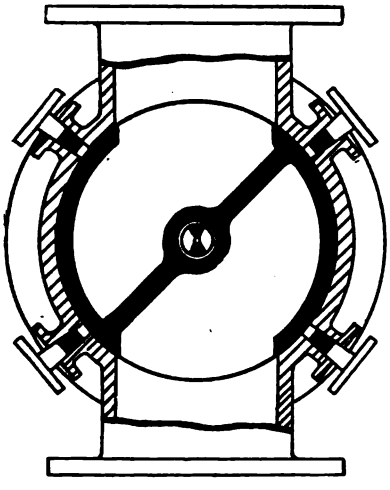


FIG. 65.—HERRING'S COAL-FEEDING DEVICE.

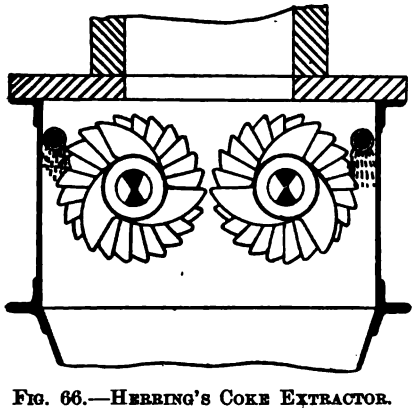


FIG. 66.—HERRING'S COKE EXTRACTOR.

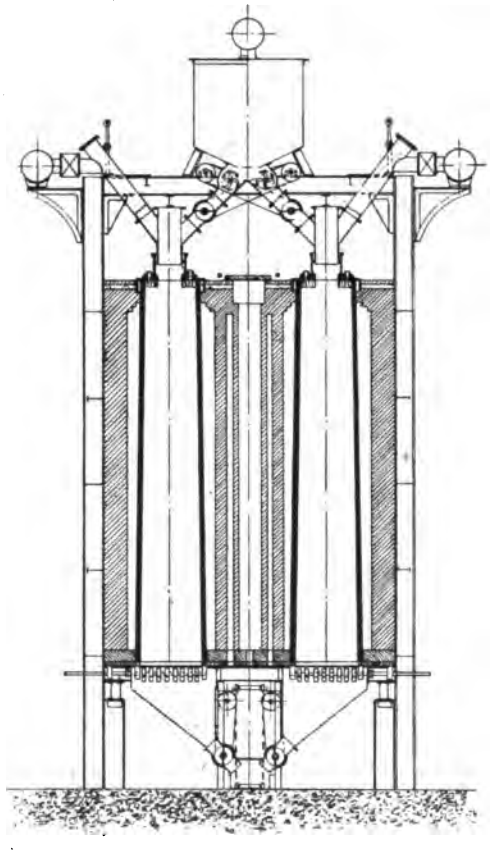


FIG. 67.—HERRING'S SYSTEM OF VERTICAL RETORTS.

coal then finds its way into the retort through an upper cylindrical pouch, to which the gas-outlet is also affixed. The coke extractor (Fig. 66) is varied in speed in accordance with the class of coal undergoing carbonization, and the coke on passing this is confined in special chambers, where it is slowly quenched. The outlet of the coke hopper is closed by a special gastight device similar to that through which the coal is admitted to the retort. Heating of the retorts takes place from the top downwards, so that the newly charged coal passes at once into the highest

temperature zone. Pyrometric tests conducted by Mr. Herring showed that the temperature varied from 2,064° Fahr. towards the top to 1,562° Fahr. at the base. The following are the more important particulars connected with the installation :—

Shape of retorts	Rectangular.
Total length	25 feet.
Breadth and width : Top	39 inches by 11 inches.
Base	48 inches by 20 inches.
Coal carbonized per retort per 24 hours	70 cwts. Scotch common coal.
Average yield per retort per 24 hours	38,000–39,000 cubic feet.
Number of retorts set in each bed	6.
Capital cost for complete bench, exclusive of foundations, but inclusive of coal-handling plant, coke-handling plant, etc. (house not included)	£148 per ton of coal per max. diem.
Make per square foot of ground area	370 cubic feet per diem.

The outside producers are, of course, fed with cold coke and are subjected to steaming. The free space in the retort is adjustable at will by regulation of the coal feed ; and the gas is taken off to a dry main. The approximate time occupied by the coal in travelling from the top to the base of the retort is twenty-four hours.

THE HOLMES-WINSTANLEY SYSTEM

The Holmes-Winstanley system has many unique features, which have been introduced to simplify as much as possible both the construction and operation of vertical retorts. The first installation on this principle was erected by Mr. Alexander Waddell, of Dunfermline.

These retorts may be arranged so as to discharge continuously by a power operated device or (as is preferable in small installations) at convenient intervals by hand. Fig. 68 shows a cross-section of the setting. The coal is fed into a hopper which is in direct communication with the retort and holds a twenty-four hours' supply of coal. This is a feature peculiar to this system. The hopper may be fed from small hand-propelled bogies, telpher skips, or travelling hoppers, as may be convenient. A patented feeding door is provided in the top of the hopper, which engages automatically with the bogie, skip, etc., on the latter being brought into position over the hopper, and opens and closes without allowing any escape of gas. The contents of the retort, as will be seen from the sketch, are under constant pressure from the column of coal in the hopper, the " free space " being practically confined to a small pocket formed at the gas outlet.

By this arrangement the formation of dust is avoided and the gas has to pass through a considerable area of comparatively cold coal before leaving the retorts. The coal in the hoppers may be replenished at any convenient intervals, or the hoppers may be filled up once only during the twenty-four hours. In cases where heavily coking or small coal is intended to be carbonized, it has been found to be an advantage to provide an auxiliary gas take-off about half-way down the retort.

In the original design (having chiefly in view the requirements of medium sized and small works), as easy a means of taking away the coke as possible without the

assistance of constantly moving machinery was considered necessary, and it was decided that this could be effected by bringing the discharging point well to the outside of the structure by adding a "right angle" shaped chamber to the retort proper, with a mouthpiece in the outer wall of the setting. The mouthpiece lid being open, the coke may be received into a tipping wagon, skip, or conveyor, as the case may be. The wagon is most suitable for small installations, and the amount of coke withdrawn may be more easily regulated by this means. A safety door is fitted inside the discharging chamber, actuated by a hand-lever, by means of which the flow of coke from the mouthpiece may be controlled, or stopped altogether, as desired. The discharging chamber and the lower portion of the retort together constitute a cooling chamber for the coke.

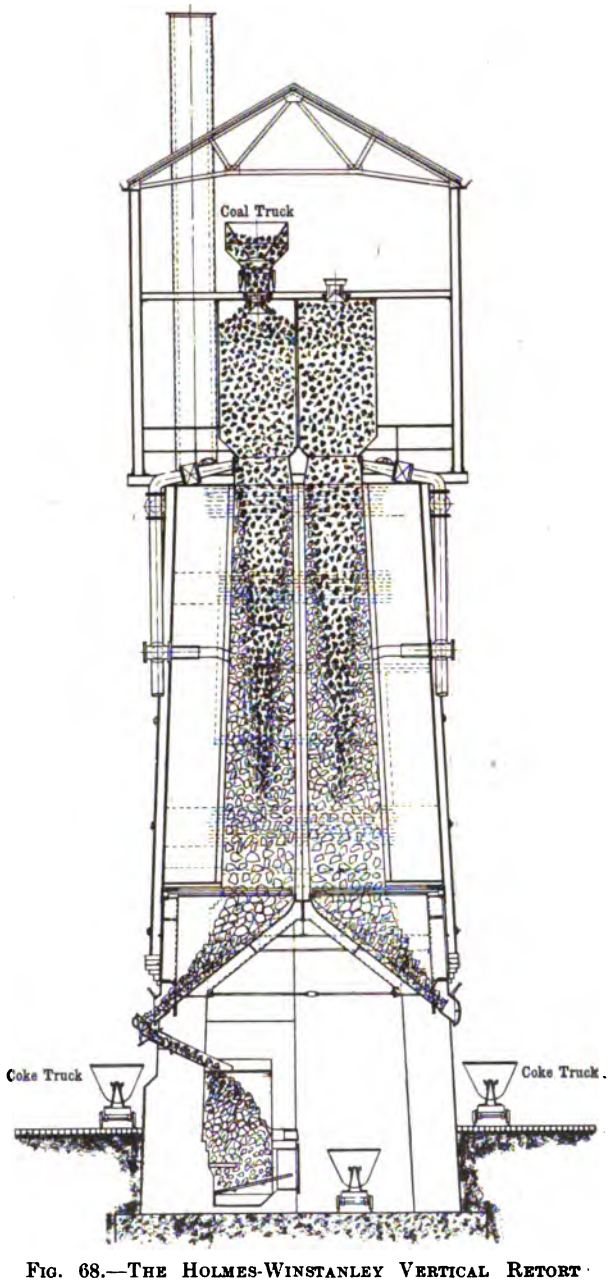


FIG. 68.—THE HOLMES-WINSTANLEY VERTICAL RETORT SYSTEM.

For large installations a continuous discharge operated by power is provided for, wherein a sliding pusher enters alternately the inner end of the retorts, set back to back, pushing the coke forward to a receiving chamber, which takes the place of the mouthpiece in the outer wall of the setting. By means of a movable shoot the furnaces are charged direct from the retorts on one side of the setting. The clinkering of the

producer is effected at the inner side, in the space between the supporting walls of the setting.

The Holmes-Winstanley retort is heated by means of a series of horizontal combustion chambers arranged between the side walls of the retorts. The gases rising from the producer meet the secondary air in the bottom chamber and pass upwards through the combustion chambers to the stack. Ports and baffles are arranged in each chamber so that the combustion may be controlled to suit the heat requirements at any point in the retort, from outside. Separate steel chimneys are provided for each setting. The retorts may be arranged in settings of 2's or 4's. There are no special bricks employed in the construction of the retorts.

In small works the power and machinery necessary to elevate the coal to the desired height is the most serious problem to be considered when installing verticals. The provision of the large hoppers with these retorts renders overhead bunkers on small installations unnecessary, and by using coal bogies holding, say, one ton of coal, a lift, either hydraulic or electrical, is all that is required to handle the coal. Coal breakers, storage bunkers, etc., on the ground floor may be arranged to communicate direct with the foot of the lift well.

KOPPERS' CHAMBER OVENS

These ovens have been extensively adopted on the Continent for gasworks carbonization, and a large installation is at work in this country at the Saltley works of the Birmingham Corporation. So far as the quality of coke-oven gas is concerned, this can be said to compare very favourably with coal gas so long as the practice of benzol "stripping" is avoided. In Germany the distribution of coke-oven gas has been carried out on a comparatively large scale, one of the chief centres being Waldenberg, which provides for the greater part of the Silesian Plain by means of long-distance transmission systems. At Mülheim the company guarantee a minimum calorific power of 600 B.Th.U. per cubic foot, but in this case only the portion of the gas evolved during the most favourable period of carbonization is diverted for town's purposes. So far as this country is concerned, a certain amount of caution has been displayed in the adoption of the gas, though recent converts are the towns of Middlesbrough and Leeds, where a supply is taken from the adjacent ovens. As regards the transmission of the gas, it seems to lose little of its value in travelling long distances, and in Germany pipe-lines of great length have been laid.

In the Birmingham installation of Koppers' chamber ovens the ovens themselves are 35 feet long, 8 feet 10 inches high, and taper in width from 19½ inches to 18 inches. Each is capable of taking a charge of from eight to ten tons of coal, the average period of carbonization being twenty-four hours. The arrangement of regenerators (Fig. 70) is unique, each oven being supplied with its separate system, consisting of a chamber (C) divided vertically into two compartments. The secondary air flows through one of these chambers and the gas through the next, and so on; the two meeting at the bottom of a vertical combustion chamber (E) extending to very nearly the same height as the oven. The products of combustion then pass into a common horizontal flue (G), over a parting wall, and down vertical flues similar to

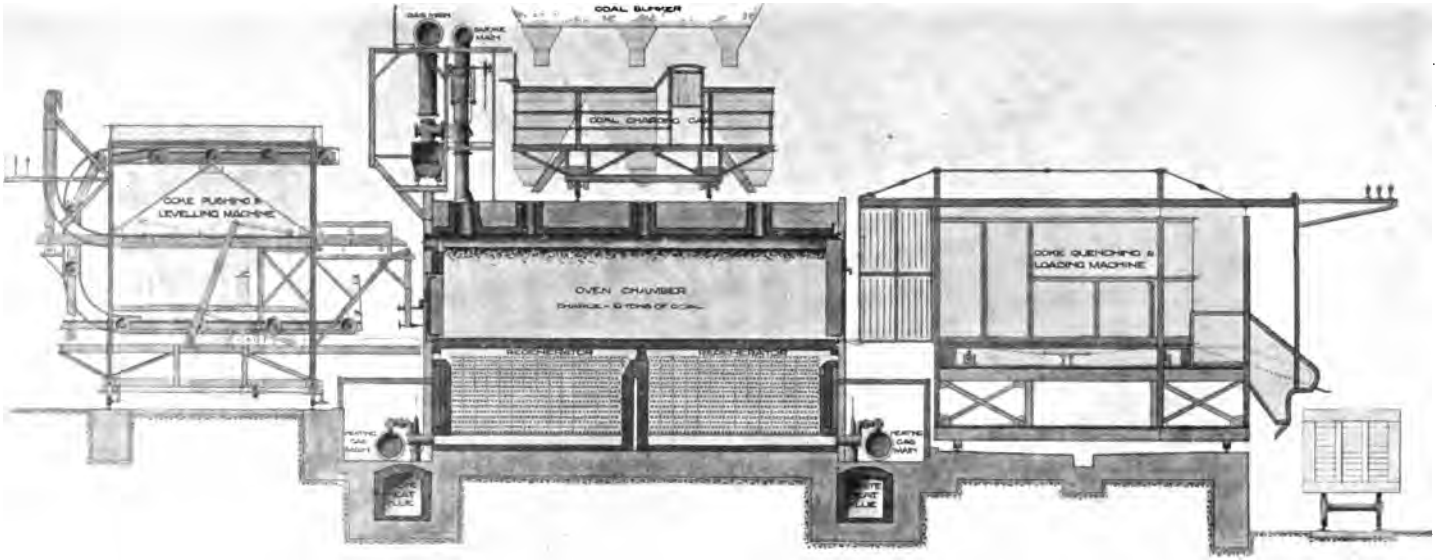


FIG. 69.—KOPPERS' CHAMBER OVEN SYSTEM.

the combustion chambers, thence to the regenerators and main flue. By means of a special change-over gear an interchange is effected between the preheating chambers of producer gas and secondary air ; that is to say, the air is admitted to those chambers previously taking gas, and *vice versa*. In this way the preheating of both air and gas is arranged for, the change-over taking place about every half-hour. In the majority of these plants the gas from the ovens themselves is used for maintaining the working heats ; but in the Birmingham installation, as before explained, the heating is carried out by means of low-grade gas from a Mond producer. The regulation of the gas to each chamber is arranged for by means of adjustable metal

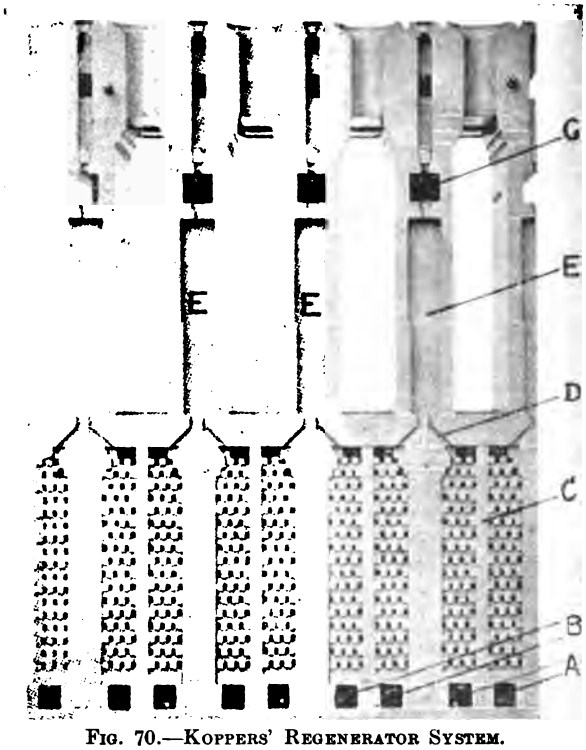


FIG. 70.—KOPPERS' REGENERATOR SYSTEM.

cocks, and the quantity passing forward is also dependent upon the pressure from the Mond producers. For the production of a dense metallurgical coke the coal is first ground in a special form of disintegrator to a fine dust, and is then delivered to the "stamping machine," where it is compressed into a solid cake of practically the same dimensions as the oven, and introduced through the end door. For many purposes unstamped coal may be made use of, in which case charging takes place by means of a machine running along the top of the settings and discharging through hoppers into three openings in the roofs of the chambers. The coal is afterwards levelled by a machine travelling alongside the setting, the latter machine being also provided with a ram for the purpose of discharging the coke at the end of the car-

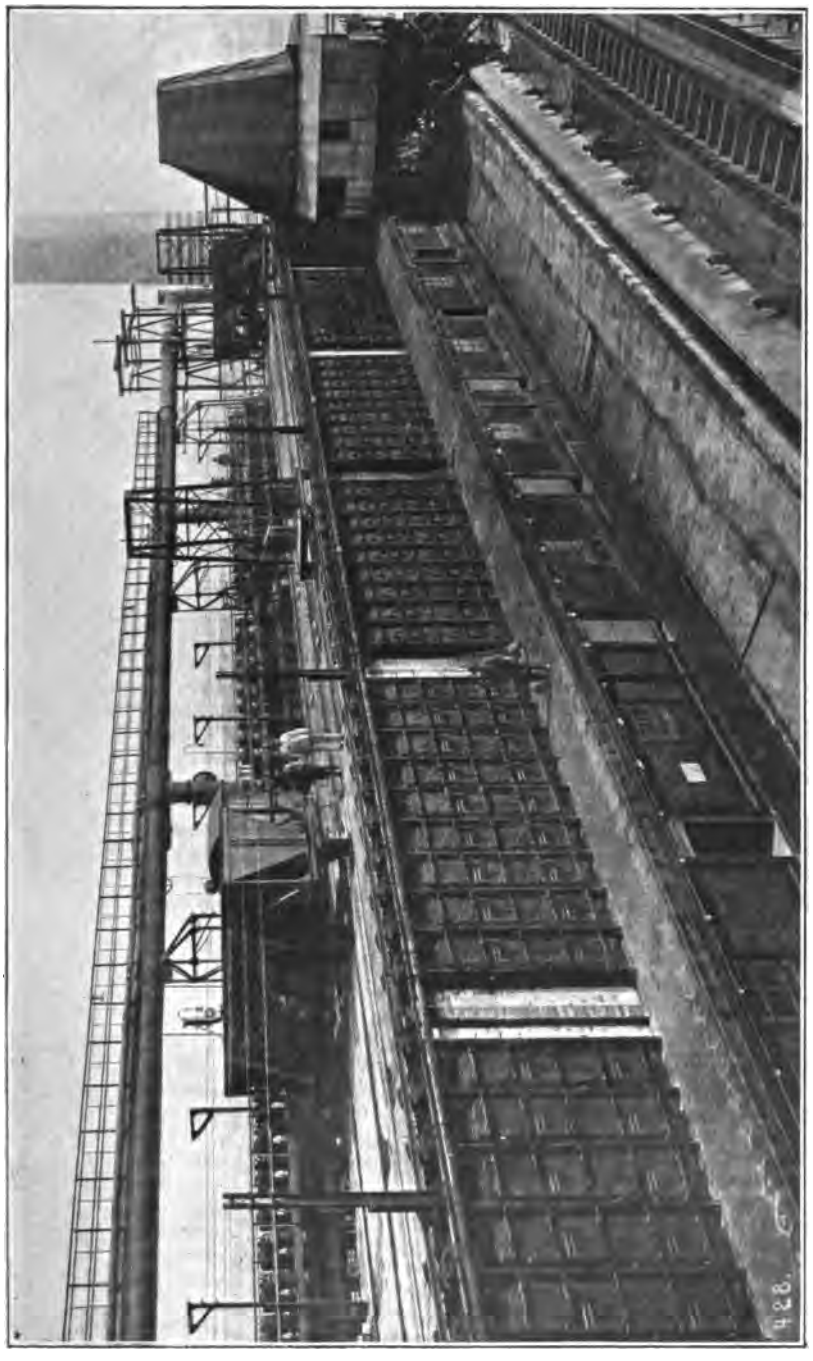


FIG. 71.—A BENCH OF KOPPERS' CHAMBER OVENS.

bonization period. The operation of discharging usually takes about five minutes. The self-sealing oven doors are cooled by a water circulating arrangement round the frame of the door.

MUNICH CHAMBERS

A noteworthy system of carbonization in bulk which is finding its way into this country is the chamber-oven plant designed by Herr Ries, of the Munich gas-

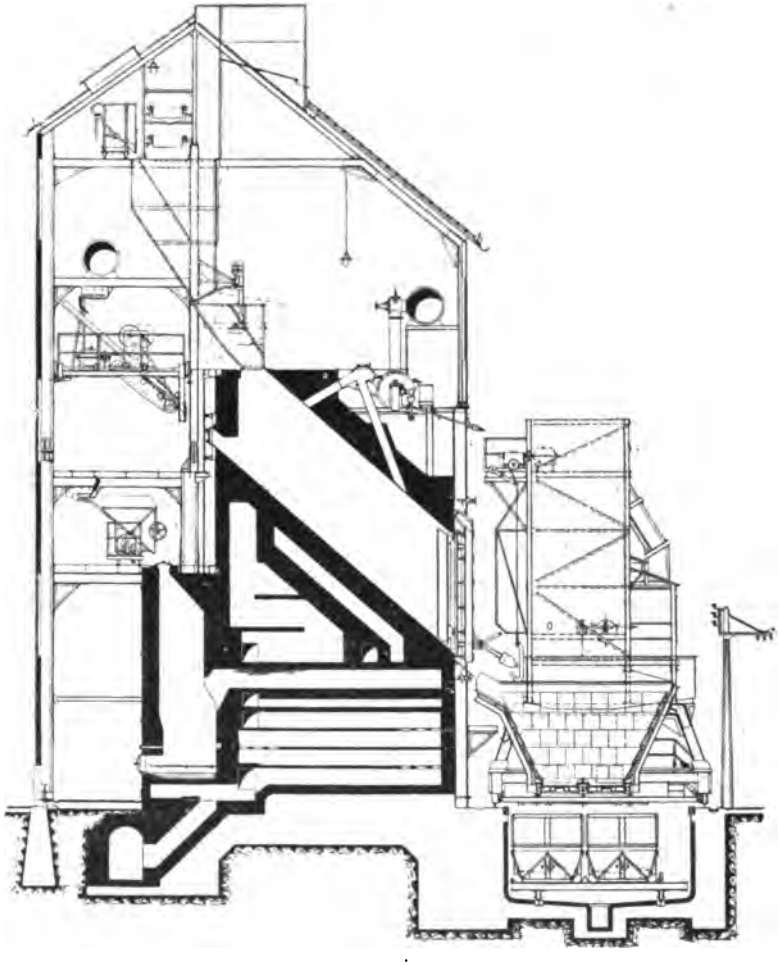


FIG. 72.—MUNICH CHAMBER OVEN SYSTEM.

works. The chamber consists of a tapered inclined coke oven. There are three or more of these in each setting, set at angles varying from 40°–42° with the horizontal. They are constructed from special keyed bricks and charged from an opening on the top of the beds. Coal is elevated to continuous overhead hoppers and directed

into the ovens by means of a special shoot. Some idea of the rapidity of charging can be gained from the fact that in the most recent installations only twenty-five seconds is required for the complete filling of a chamber taking from seven and a half to eight tons. Owing to the moderately sharp incline at which the chambers are set, the coke will in many cases discharge itself without any outside assistance, but in order that any tendency to hang up may be avoided, a light starting-ram is provided to set the carbonized charge in motion. The discharger consists of a light

FIG. 73.—BENCH OF MUNICH CHAMBER OVENS SHOWING COKE-QUENCHING MACHINE.

" link-coiling " ram geared to an electric motor; and the pusher, by means of suitable guides, is constrained to move in a straight line, following the angle of the oven which it enters. As a general rule the complete charge is dispatched in about forty seconds. The oven doors, which are extremely massive, are raised by an electric hoisting motor, and the incandescent coke runs direct into a specially designed coke-quenching machine. The chamber door is then lowered, and automatically engages itself in a special fastener for ensuring a hermetical seal. In the Munich installation the coke-quencher consists of a mild-steel receiving hopper surmounted

by a ferroconcrete shaft of square section for the purpose of conducting the steam to a considerable height before its escape into the air is permitted. After quenching has been partly carried out by means of a spray at the head of the hopper the coke goes into a swing-boat conveyor, cased with steel plates, which scrapes it through a bath of water and delivers it, fully quenched, to a de Brouwer conveyor. The coke is then carried on to a screening and sorting plant. Outside producers have in some instances been employed for heating the ovens; but, in general, each bench of three is provided with a self-contained producer, the fuel consumption averaging from 14 to 15 per cent. of the coal carbonized. A feature of the producer is the water-cooled grate, which, in conjunction with the steaming employed, practically obviates ordinary clinkering. At the Altona works at Hamburg a plant was put to work in November, 1913, and between then and the end of March, 1914, clinkering was only resorted to on one occasion. The furnaces do, however, require some attendance, and "pricking-up" is regularly carried out every eight hours. Any class of coal can be charged into the ovens so long as the lumps do not exceed 10 × 15 inches in size. Much depends, however, on the type of coke required. For a semi-coke the temperature of carbonization is kept down to 1,100° Fahr.; whilst for furnace coke the coal is ground extremely fine, carbonized at 2,000° Fahr., and steamed in the bunkers with exhaust steam so as to add the requisite 10 per cent. of moisture. At the Tegel works, Berlin, there are eighty-one of these ovens at work, carbonizing 567 tons of coal per diem. An idea of the labour entailed can be gleaned from the fact that eighteen men are required for an output of 7,000,000 cubic feet in twenty-four hours. At the Moosah gasworks, Munich, there are now eighty-seven ovens at work.

The salient features of the Munich chamber system are given below :—

Shape of chamber	Rectangular tapered.
Slope	40–42° with horizontal.
Length	26 feet (actual length of sloping floor line).
Mean width	1 foot 9 inches.
Height	9 feet 10 inches.
Coal carbonized per chamber per 24 hours	2½ to 8 tons, as desired.
Average yield of chamber per 24 hours	100,000 cubic feet.
Number of chambers set in a bed	2, 3, 4, or 5.
Duration of charge	24 hours.
Grate area of setting	8 to 16 square feet.
Costs.—Complete bench, including foundations, coal-handling plant, power-operating plant, coke-handling plant, etc., but exclusive of building	£230 per ton of coal per diem.
Cost of housing	£5 to £9 per ton of coal per diem.
Working charges	1½*d.* to 3*d.* per ton of coal, according to size of installation.

NORWICH CHAMBERS

At a time before the merits of the fully charged horizontal retort were realized Mr. Thos. Glover introduced at Norwich a special form of semi-chamber retort.

These chambers, which were 21 feet long, 3 feet high, and 1 foot wide, were fully charged by means of a de Brouwer projector. The average coal charge amounted to 21 cwts., and was distilled for a period of twelve hours. Compared with partly filled horizontals the results were a decided improvement, but it was eventually found that heavily charged horizontal retorts of the normal size gave equally satisfactory yields, and the system was ultimately abandoned.

COMPARATIVE FEATURES OF VARIOUS

	Horizontal Bench.	Woodall-Duckham Verticals.	Glover-West Verticals.
	Intermittent.	Continuous.	Continuous.
Shape of retort	⌂	Rectangular, tapered	Oval
Dimensions—Length	20 feet	25 feet	19 to 25 feet
Breadth and width—Top	24 inches × 16 inches	3 ft. 10½ in. × 8 in.	From 27 in. × 12 in. to 33 in. × 8 in.
„ „ Bottom	Do.	5 ft. 3 in. × 18½ in.	From 36 in. × 21 in. to 39 in. × 18 in.
Coal carbonized per retort per 24 hours	1½ tons	4½ to 5½ tons [1]	2½ to 3½ tons
Yield per retort „	20,000 cubic feet	60,000 to 70,000 cubic feet [1]	35,000 to 40,000 cubic feet
No. of retorts set in each bed	8 to 12	2 or 4	Usually 8
Duration of charge	8 to 12 hours	Continuous	Continuous
Grate area per setting	20 square feet	7 square feet per retort	7 square feet per retort
Producer charged with	Hot coke	Cold coke	Cold coke
Is coal charge steamed?	No	No	No
Average yield per square foot of ground area per diem (outside dimensions of house)	200 to 250 cubic feet	350 to 475 cubic feet [2]	400 cubic feet
Capital costs (complete bench, including foundations, coal-handling plant, power-operating plant, coke-handling plant, but exclusive of house, per ton of coal per maximum day)	£110 to £140 [2]	£140 to £180 [2]	£150 to £170 [2]
Cost (as above) per 1,000 cubic feet per maximum day	£9·5 [2]	£10 to £14 [2]	—
Cost of house (with foundations) per ton of coal per maximum day	£45 to £65, inclusive of 3 weeks' coal storage	£25 to £45,[2] exclusive of coal stores	£30,[2] exclusive of coal stores
Working costs per ton of coal (total labour in retort house)	1*s.* to 1*s.* 6*d.*[5]	7½*d.*[3]	4½*d.* to 6*d.*[3]
Approximate time occupied by coal in travelling from entrance to exit of retort	—	7 to 8 hours	12 hours
Speed of coke extractor	—	1 revolution in 50 to 70 minutes [1]	1 revolution in 30 to 40 minutes [1]
Coke quenched	Water spray	By primary air circulating round base of retort	By secondary air circulating round base of retort
Method of heating	Equal distribution	Top heating	Bottom heating
Gas take off	Wet or dry main	Wet main	Dry main

[1] According to class of coal carbonized. [2] According to size of plant. [3] Scotch common coal.
[4] This is exclusive of foundations. [5] In exceptional cases as low as 9*d.*

N.B.—All costs (both for capital and labour) given above are liable to considerable variation in

SYSTEMS OF CARBONIZATION.

Dessau Verticals.	Glasgow Verticals.	Herring's Verticals.	Koppers' Chamber Ovens.	Munich Chambers.
Intermittent.	Continuous-intermittent.	Continuous.	Intermittent.	Intermittent.
Oblong with round corners	Rectangular	Rectangular	Rectangular, tapered	Rectangular, tapered
5 metres (16 ft. 5 in.)	20 or 23 feet	25 feet	35 feet	26 feet
21 inches × 8½ inches	40 inches × 10 inches	39 inches × 11 inches	Width, 18 inches to 19½ inches	Mean width, 21 inches
27 inches × 14 inches	48 inches × 18 inches	48 inches × 20 inches	Height 8 feet 10 inches	Height, 9 feet 10 inches
22¼ cwts.	3 tons	3½ tons [3]	8 to 10 tons	2 to 8 tons
15,000 cubic feet	31,500 to 37,500 cubic feet [1]	39,000 cubic feet	100,000 to 120,000 cubic feet	100,000 cubic feet
4 to 18	4, 6, and 10	6	—	2, 3, 4, or 5
12 hours	Portion of coke drawn every 4 hours	Continuous	24 to 30 hours [6]	24 hours
5 square feet per retort	4 square feet per retort	External producer	External producer	16 square feet
Cold coke	Cold coke	Cold coke	Slack coal or mixture	Cold coke or fine breeze
Steamed for last 2 hours	Yes, if desired	No	Wet coal carbonized if desired, otherwise no	No
250 to 350 cubic feet [2]	350 to 400 cubic feet	370 cubic feet	—	500 cubic feet
£150 [2]	£142 [2]	£148 [4]	£180 [2]	£230 [2]
£10·7 [2]	£11·5 [2]	£13·5 [4]	£14	£18 [2]
£20,[3] exclusive of coal stores	£23.[2] exclusive of coal stores	—	—	£5 to £9, exclusive of coal stores
4*d.* to 6*d.*[2]	3*d.*[7]	—	8*d.* to 10*d.*[2]	1½*d.* to 3*d.*[2]
—	18 hours	24 hours	—	—
—	Coke drawn every 4 hours	—	—	—
Water spray	Cooled in bottom chamber	Slowly cooled in bottom chambers	Water spray	Water spray
Bottom heating	Top heating	From top downwards	Equal distribution	Equal distribution
Wet or dry main	Wet main	Dry main	Dry main	Dry main

[6] According to whether coal is stamped or unstamped, or wet or dry. [7] Carbonization only.

accordance with the prevailing costs of material and labour, also the size of the installation.

CHAPTER VI

REFRACTORY MATERIALS

ONLY within comparatively recent years has the study of various types of fireclays and their relative merits for retort bench and other purposes received more than passing attention from the gas engineer. The developments of present-day research, however, has been the means of creating a new science, with the result that refractory materials and their application have become one of the most significant branches of modern gasworks' practice. Detailed discussion of the origin of clays is without the scope of the present book, but it is proposed to consider the question in a more or less practical manner, with special reference to those features by which the designer and purchaser should be influenced.

The word "refractory" in reality is merely a comparative term, and in the literal sense means "unable to melt." A wide range of substances is included under the classification of refractory materials; among these, in addition to the more common types of fireclays, being carborundum, alundum, diamantin, quartz, etc. No material is completely refractory; that is to say, all so-called refractory substances are capable of fusion, but their respective yielding points are abnormal in comparison with prevailing working temperatures.

Stated in brief, fireclays are the result of the decomposition of the feldspathic constituents of particular rocks subjected for untold years to the destructive influence of weathering. Differing degrees of the process of weathering account for modifications in the type of clay produced, and only in rare instances is the process so complete that the final stage (*i.e.*, reduction to true clay substance, kaolin or china clay) is reached. The evolution of the true clay substance from the feldspars in the presence of carbonic acid and water may be chemically expressed as follows :—

$$Al_2O_3.K_2O.2(3SiO_2) + 2H_2O + CO_2 = 4SiO_2 + K_2CO_3 + Al_2O_3.2SiO_2.2H_2O \text{ (kaolin)}$$

These kaolin clays are highly refractory but are practically devoid of plasticity; they exist, however, in relatively small quantities, and the larger deposits of fireclays of service to the gas engineer are the result of incomplete or intermittent weathering. It should be stated here that although, as a general rule, the refractoriness of a substance may be gauged by the proportion of silica it contains, this proposition is by no means beyond question, and definite combinations of silica and alumina are more highly infusible than when the latter gives way to silica. In fact, certain experimenters have shown that alumina is rather more refractory

than silica, and that by admixing the two so as to give the composition $Al_2O_3.2SiO_2$ (*i.e.*, true clay substance, *see* above equation) the most infusible product is obtained. Ordinary fireclays may in general be denoted by the formula—

$$Al_2O_3.6SiO_2$$

but in addition to the silica and alumina they contain varying quantities of impurities, such as oxides of calcium, magnesium, titanium, potassium, sodium, and iron. These impurities, owing to their low fusibility, exert a most harmful influence on the ultimate refractoriness of the clay, and in any case their total content should be limited to 4 or 5 per cent. Much depends, however, on the type of clay in question, and some highly refractory materials now used contain as much as 4 per cent. of iron alone. Chief objection to impurities lies in the fact that once they themselves have set up fusion by the formation of fusible silicates the remainder of the material may fall a victim to their influence, even though the prevailing temperature is considerably below the normal fusing point.

Many recent investigators into the refractoriness of clays have emphasized the fact that ultimate chemical analysis cannot be taken as a final indication of infusibility; in fact, instances have been quoted where clays having chemically a model composition have been known to give defective articles. For this reason it has been suggested that the analysis should be directed towards the presence of the various mineralogical constituents on a subdivision such as the following:—

(*a*) True clay substance.
(*b*) Quartz.
(*c*) Remnants of the original mother rocks.

The last-named component, containing the original alkaline impurities, is, perhaps, of chief importance, and for effective results should be in the neighbourhood of 2½ per cent. In the less siliceous clays the desirable kaolin will average about 72 per cent., the remainder being accounted for by quartz, which has a varying influence, chiefly dependent upon the quantity of impurities present. If the impurities are on the low side the tendency of the quartz will be to aid infusibility. An important feature in connexion with impurities is that their influence is more marked in the presence of silica than of alumina; hence deletion, as far as possible, from the highly siliceous clays is imperative. Calcium compounds are particularly to be guarded against, owing to their tendency to act as an extremely rapid and powerful flux. The ability of the various compounds classified as impurities to act as fluxes is in direct ratio to their equivalent combining weights. The most desirable means of determining the suitability of a material for high-temperature work is undoubtedly by a combination of the ultimate, rational, and mechanical analyses.

THE WINNING AND WORKING-UP OF FIRECLAYS

By far the largest deposits of aluminous fireclays in this country occur in the Stourbridge, Yorkshire, and Newcastle districts. The clay is generally found at a considerable distance below the surface, and shafts are frequently sunk to depths of 500 or 600 feet, or even more. In winning the clay, care has to be taken to avoid

mixing the products from distinct seams; for although the seams occur in close proximity to one another, their chemical constituents and properties are by no means similar. Thus, a highly desirable substance may be found adjacent to one containing an abnormal proportion of deleterious salts. After being brought to the surface the majority of clays undergo treatment known as "weathering," which has an important influence on their suitability for future use. This process is essential, in that the clay (stacked in shallow heaps for some considerable period) is subjected to thorough lixiviation, with consequent reduction of the harmful alkalis, which are usually decreased by at least 40 per cent. Once "weathering" is complete the requisite quantity of "green" clay is made up by thoroughly grinding together definite proportions of the varying types; that is to say, the clay from one particular seam is frequently not used by itself, but if of the "strong" or siliceous type, it is mixed with a certain proportion of the "mild" or aluminous quality until the desired material is obtained. The material having been moulded and dried would then be ready for burning in the kilns but for the fact that the "green" clay treated in this manner is subject to considerable shrinkage, and would in addition provide a finished article of too fine a grain for high-temperature purposes. In consequence, not the least important consideration in the manufacture of fireclay articles is the preparation and admixture of "chamotte"—a substance known in manufacturing circles as "grog,"—which reduces the shrinkage to reasonable limits and opens out the texture of the material, rendering it of greater porosity. It is because contraction takes place on burning that fireclay goods are rarely absolutely consistent as regards size, for it is impossible to foretell with perfect accuracy what the shrinkage, or "sink," will amount to. For ordinary Stourbridge firebricks the contraction on burning usually amounts to 1 inch to 1½ inches per foot, the length of a 9-inch brick being 9¾ inches before burning; whereas with gas retorts, the amount is about ¾ inch per foot, and a finished retort measuring 24 inches by 16 inches would be moulded before burning to 25½ inches by 17 inches.

The selection and preparation of "grog" has to be carried out with great care, since a superior clay may be completely ruined by the careless introduction of an inferior "grog." "Grog" is usually prepared from a clay which originated in the same seam as the fireclay with which it is to be mixed. This clay, in the form of lumps, is burnt in a kiln out of contact with the fuel; and the firing temperature should be greater, or at least as great, as that to which the finished article will be subjected. The lumps are then ground to the desired size. The quantity of "grog" added varies, of course, with the material required and the kind of clay made use of. For firebricks and smaller articles, however, it is usually added in a proportion of from 15 to 20 per cent., while for larger articles, such as retorts, the amount is increased to from 30 to 40 per cent.

On the Continent the preparation of chamotte is an industry in itself, and lumps of selected burnt clay are dispatched long distances for the use of manufacturers. In some Continental fireclays ordinary "grog" is dispensed with, and in its stead a special china clay is employed, the shrinkage of which is so small that it may be used without previous burning.

THE CLASSIFICATION OF REFRACTORY MATERIALS

Refractory materials are, in general, classified in accordance with the percentage of silica they contain. Aluminous clays are those of the Stourbridge type, containing about 65 per cent. of silica, "siliceous" those containing from 80 to 92 per cent. of silica, whilst those containing upwards of 92 per cent. are known as "silica" materials. It is the two last-named materials which are assuming great importance in present-day gasworks practice. Typical highly siliceous clays are the Dinas, Ewell, Ganister, and some Scotch varieties, the best known of the last mentioned being the Bonnybridge type. Analyses of the various materials as now used on gasworks are given below. To avoid confusion, the low silica clays, containing less than 72 per cent. of silica, and generally distinguished by the name fireclays, have been referred to—probably not strictly accurately—as "aluminous" clays.

1. Aluminous Clays. (See also under "Scotch Clays.")

Stourbridge Type.

Silica	64·62 per cent.
Alumina	21·65 „
Ferric oxide	1·48 „
Lime	1·88 „
Magnesia	0·62 „
Moisture	9·62 „

(Bywater.)

2. Siliceous Clays.

(*a*) *Ganister. Oughtibridge (Type A).*

Silica	90·2 per cent.
Alumina	7·06 „
Titanic oxide	0·36 „
Ferric oxide	1·03 „
Magnesia	0·05 „
Lime	0·40 „
Potash	0·56 „
Soda	0·30 „

(*b*) *Ewell Type.*

Silica	87·57 per cent.
Alumina	3·60 „
Ferric oxide	4·80 „
Lime	0·74 „
Magnesia	0·41 „
Potash	0·69 „
Soda	0·10 „
Water of combination	2·09 „

3. Silica Clays.

(*a*) *Dinas.*

Silica	97·6 per cent.
Alumina	0·5 „
Ferric oxide	1·5 „
Lime	0·2 „
Potash	0·09 „
Soda	0·03 „

(Bywater.)

(*b*) *Black Ganister.*

Silica	98·5 per cent.
Alumina	0·3 ,,
Ferric oxide	1·3 ,,
Lime	0·2 ,,
Potash	Traces.
Soda	Traces.

(*c*) *Oughtibridge* (*Type B*).

Silica	94·78 per cent.
Titanic oxide	0·20 ,,
Alumina	1·65 ,,
Ferric oxide	0·62 ,,
Lime	1·51 ,,
Magnesia	0·01 ,,
Potash	0·54 ,,
Soda	0·34 ,,

This material is of very similar nature to the Oughtibridge type given under siliceous clays, with the exception that this variety is manufactured with the lime bond, whereas that previously mentioned is not.

(*d*) *Bonnybridge* (*Type A*).

Silica	95·03 per cent.
Alumina	2·73 ,,
Ferric oxide	0·45 ,,
Lime	1·80 ,,
Magnesia	0·11 ,,

4. Scotch Clays (Aluminous).

(*a*) *Glenboig.*

Silica	53·26 per cent.
Alumina	42·10 ,,
Ferric oxide	2·08 ,,
Titanic oxide	1·50 ,,
Lime	Trace.
Magnesia	Trace.
Sulphates	1·06 per cent.

This analysis is somewhat flattering, and the iron content will frequently be higher.

(*b*) *Bonnybridge* (*Type B*).

Silica	61·10 per cent.
Alumina	33·64 ,,
Ferric oxide	2·40 ,,
Lime	0·72 ,,
Titanic oxide	0·89 ,,
Magnesia	0·80 ,,
Alkalis	0·45 ,,

THE TESTING OF REFRACTORY MATERIALS

In addition to the ordinary laboratory tests for the determination of ultimate analysis, refractory materials should be subjected to certain practical tests in order to determine their suitability for retort-bench purposes. The tests usually applied, and specified by the Refractory Materials Committee of the Institution of Gas Engineers, are as follows:—

(*a*) For refractoriness.
(*b*) Apparent porosity.
(*c*) Contraction or expansion.
(*d*) Crushing strength.

It must be mentioned at the outset that refractoriness is not merely dependent upon the maximum temperature which the material is capable of withstanding before fusion takes place. The rate of change of temperature has also some considerable influence, and for this reason it is specified that for tests for refractoriness the temperature of the experimental furnace shall be increased at the rate of 50°C. (122° Fahr.) during five minutes. There are various furnaces suitable for the purpose, but the electrical apparatus of Hirsch, or the Méker air-gas type, are to be preferred.

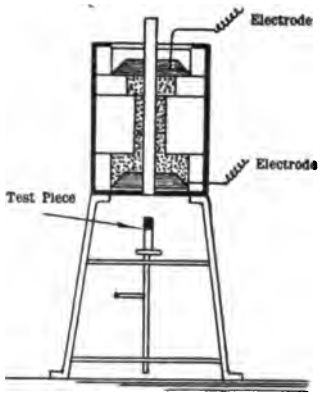


FIG. 74.—HIRSCH'S ELECTRIC FURNACE.

The Hirsch furnace (Fig. 74) is of the resistance type, the resistance material used being chiefly carbon. The current is led into the furnace by means of the two electrodes shown, these being of iron and embedded in a large area of carbon, which tends to keep them cool. The volume of carbon in the centre of the furnace is made smaller, so that the heat is concentrated here. To attain the maximum temperature the furnace requires a current of 130 amperes at 70 to 80 volts. The clay to be tested is mounted on the top of the cylindrical support and introduced into the centre tube of the furnace, this tube having an internal diameter of $2\frac{1}{2}$ inches. The appearance of the sample undergoing test can be watched by looking down the centre tube from the top. A weak current of air constantly passes through the centre tube, the object of this being to overcome the reducing atmosphere always associated with carbon resistance furnaces.

The Méker furnace (Fig. 75) is capable of giving a temperature up to 1,850° C. (3,360° Fahr.). The main feature of the apparatus is the special type of Méker burner, requiring compressed air under a pressure of from 10 to 30 lb. per square inch; whilst, for effective results, the gas pressure should not be below $1\frac{3}{8}$ inches. A crucible of special refractory material is mounted on a support, and the flame

from the burner, passing through the base of the support, surrounds the crucible, and is then turned downwards to its outlets.

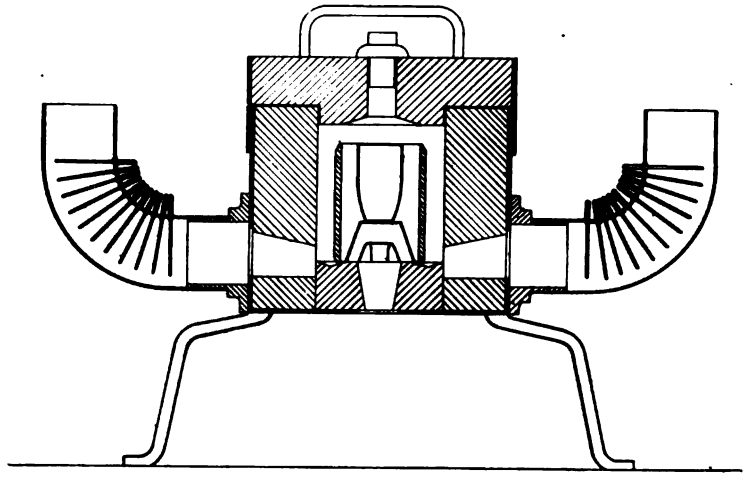


FIG. 75.—THE MÉKER AIR-GAS FURNACE.

Seger cones (Fig. 76), which partially fuse, or "squat," at predetermined temperatures, are found to provide the most convenient means of recording the approximate yielding points of the samples under test. The Refractory Materials Committee state that two or more tests are generally required when an unknown material is being dealt with. "A preliminary trial is first made with a piece of the material chipped into the approximate form of a cone. This should be cemented on to the refractory slab of the test furnace with a mixture of alumina and best china clay, together with Seger cones 28, 30 and 32 (small size). Best china clay fuses between cones 35 and 36; and all British fireclays fall below this point. If cones 28 and 30 fall, the furnace should be cooled, and the material under investigation examined. If it exhibits no sign of fusion, the trial should be repeated with cones 30, 31 and 32. By this method of approximation it is possible to decide whether the piece vitrified between cones 30 and 31 or between cones 31 and 32. The cones should, in all cases, be placed relative to the sample so that both are subjected to the same temperature. It should be noted that clays and related materials have no sharply defined melting points, and the definition of refractoriness adopted refers to the temperature at which the angular edges of the material begin to lose their angularity when heated under the conditions stated."

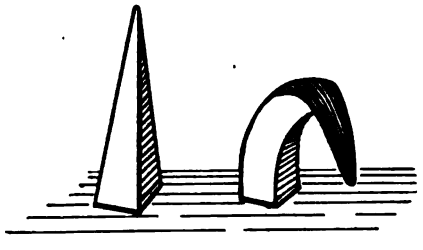


FIG. 76.—SEGER CONES.

SOFTENING POINTS OF SEGER CONES.

Cone No.	Cent.	Fahr.	Cone No.	Cent.	Fahr.
022	600	1112	9	1280	2336
021	650	1202	10	1300	2372
020	670	1238	11	1320	2408
019	690	1274	12	1350	2462
018	710	1310	13	1380	2516
017	730	1346	14	1410	2570
016	750	1382	15	1435	2615
015a	790	1454	16	1460	2660
014a	815	1499	17	1480	2696
013a	835	1535	18	1500	2732
012a	855	1571	19	1520	2768
011a	880	1616	20	1530	2786
010a	900	1652	26	1580	2876
09a	920	1688	27	1610	2930
08a	940	1724	28	1630	2966
07a	960	1760	29	1650	3002
06a	980	1796	30	1670	3038
05a	1000	1832	31	1690	3074
04a	1020	1868	32	1710	3110
03a	1040	1904	33	1730	3146
02a	1060	1940	34	1750	3182
01a	1080	1976	35	1770	3218
1a	1100	2012	36	1790	3254
2a	1120	2048	37	1825	3317
3a	1140	2084	38	1850	3362
4a	1160	2120	39	1880	3416
5a	1180	2156	40	1920	3488
6a	1200	2192	41	1960	3560
7	1230	2246	42	2000	3632
8	1250	2282	—	—	—

TESTING UNDER STRESS

Although the conditions of testing in furnaces such as described above coincide with those prevailing in a retort setting in respect of temperature, it must not be forgotten that the fireclay material forms part of a structure, and is, in consequence, subjected to varying degrees of stress (chiefly compressive) according to its function in the setting. In this respect a series of tests have been carried out by Dr. J. W. Mellor [1] to determine the effect of stress upon ultimate refractoriness. The effects of comparatively light loading are certainly a matter for surprise, and a decrease in refractoriness of from 12 to 13 per cent. has resulted from loading equivalent to 54 lb. per square inch.

[1] Report of Refractory Materials Committee, 1914.

APPARENT POROSITY

The test for apparent porosity really indicates the density of the material, and gives the percentage of the total volume which is occupied by air spaces.

$$\text{Percentage porosity} = \frac{\text{Volume of air spaces}}{\text{Total volume of test piece}} \times 100.$$

Porosity is one of the most important properties of present-day fireclay articles, and is determined by means of some forms of " voluminometer " or " porosometer," as shown in Fig. 77. The piece to be tested should be of the size of half a brick, having a volume of about 700 c.c. The principle of the test is based on the absorption by the brick of a suitable liquid (usually paraffin) until the air spaces and cavities are completely filled. The volume of liquid required for this purpose can be measured in the burette, this being identical with the volume of the air spaces, hence the porosity may be determined. The test piece, dried at 100° C., is placed in the glass jar; the paraffin from the latter having been previously sucked up into the burette by means of a water pump. Another water pump is then connected to the lid of the jar containing the test piece, and as much air as possible is sucked out. With the pump still working, the paraffin is then allowed to enter the jar slowly until the brick is completely covered, the pump sucking away the air from the interstices of the brick, paraffin taking its place. By levelling and reading the burette, the volume of liquid displaced by the solid portion of the test piece will be given. The volume of the soaked brick is then found by displacement in a similar manner, thus giving the total volume of the test piece, and the percentage porosity calculated as above.

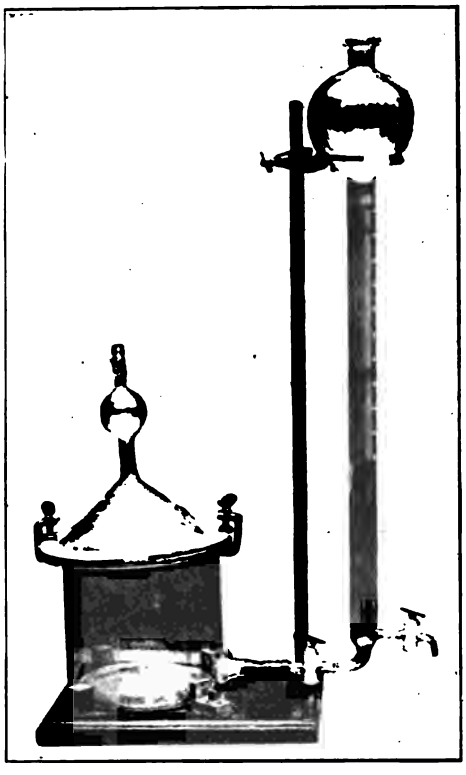


FIG. 77.—MELLOR'S POROSOMETER.

LINEAR CONTRACTION OR EXPANSION

By this is meant the percentage change in length which occurs when the test piece is heated under stated conditions. " A carborundum wheel may be used for grinding the ends of the test pieces flat, and one of the Méker furnaces may be employed for carrying out the test. The test piece should be supported horizontally,

and fired along with cones 13, 14 and 15. As soon as cone 14 has squatted, it ceases to furnish any further indication of the temperature of the muffle; so that the subject temperatures should be ascertained at about 15-minute intervals, by means of a pyrometer. It is essential, however, that the temperature should remain constant; and if it is necessary to remove plugs, etc., for the purpose of obtaining the temperature, great care must be taken to avoid cooling the furnace by such means. As in the test for refractoriness, the cones should be placed in such a position relative to the sample under test that both may be subjected to the same temperature."

The Refractory Materials Committee specify the following limits for various materials so far as contraction or expansion is concerned:—

Retort Material.—A test piece heated to a temperature of cone 14 (2,570° Fahr.) for two hours shall not show, when cold, more than 1¼ per cent. contraction or expansion. The test piece is to be 4½ inches long by 4½ inches wide, with the ends ground flat. Readings as to length are to be taken by means of Vernier callipers reading to 0·1 mm.

Firebricks, Blocks, and Tiles.—A test piece when heated under the above conditions shall not show more than 1 per cent. or 1¼ per cent. contraction or expansion, according to the grade of material.

Silica Articles.—A test-piece when heated for two hours to a temperature of cone 12 (2,462° Fahr.) shall not show, when cold, more than 0·75 per cent. linear contraction or expansion.

CRUSHING STRENGTH

The compressive strength of fireclay articles may be determined by means of one of the forms of apparatus made for the testing of materials. With regard to ordinary Stourbridge articles, these should be capable of withstanding a crushing stress of not less than 1,800 lb. per square inch.

THE RELATION OF REFRACTORY MATERIALS TO THE VARIOUS PORTIONS OF A RETORT SETTING

In dealing with fireclay articles and their relation to the various portions of a retort bench, it is proposed to consider the matter from the purely practical standpoint of the gas engineer, and to avoid, so far as possible, the inclusion of abstruse technical details, which are of chief concern to the scientist and investigator. Such prominence is given nowadays to the question of refractory materials that every gasworks official is more or less an authority on the subject. It must be admitted, however, that it is chiefly the technical manufacture of the articles around which argument is waged, whereas the everyday facts concerning the suitability of various materials for some particular function receive but a meagre share of attention. Errors of judgment in the selection of fireclays are only too common, even in the present semi-enlightened age; and, undoubtedly, considerable trouble and expense could be avoided if, in the first place, the purchaser studied his requirements on methodical lines. To this end, it is suggested that the conditions which any particular

material may be called upon to withstand should be subjected to a preliminary investigation on lines such as the following:—

1. Is the temperature high or moderate? "Moderate" may be considered up to 1,850° Fahr. "High," up to 2,800° Fahr. As a matter of fact, the latter temperature should seldom be necessary in the modern combustion chamber; the figure being usually in the neighbourhood of 2,500° Fahr.

2. Will there be fluctuations of temperature? This is one of the most trying conditions which the material can be called upon to withstand. If the setting is worked correctly there should be nothing in the way of violent fluctuations, except, perhaps, in the retorts. It must be remembered that there may be so great a fall in temperature as 1,000° Fahr. when a retort is freshly charged.

3. Will the material come into direct contact with the flame, or will there be a "cutting heat"? By a "cutting heat" is usually understood a fierce, localized flame, the effect of which is exaggerated by the presence of flue dust in the gases. This dust may contain upwards of 50 per cent. of injurious iron compounds.

4. Is mechanical strength required? Various portions of the retort bench take their place in ensuring the stability of the structure; hence, in addition to withstanding high temperatures, they are called upon to withstand working stresses.

5. Is heat to be conducted or retained? This is a point which arises chiefly when deciding upon material for regenerators and the external walls of settings. In order to prove a good conductor of heat, the material must be dense, and manufactured with as close a grain as possible. On the other hand, for the retention of heat the texture must be as open as possible; which accounts for the extreme lightness of many of the insulating bricks (such as "Thermalite") now to be obtained.

6. Is the material likely to be affected by external fluxes? The small percentage of low-fusing constituents present in the fireclay is more or less harmless when left to itself; but if incipient "slagging" is set up by other fusible substances introduced from outside, there is no telling where the trouble may end. Iron dust in the producer gases and clinker adhering to the sides of the furnace walls are the chief offenders in this direction.

7. Will the material be subjected to an oxidizing or to a reducing atmosphere? A reducing atmosphere (*i.e.*, an atmosphere of carbon monoxide) is more trying than oxidizing conditions; but if a retort bench is being correctly operated, the only possible point at which a reducing atmosphere could continuously prevail would be above the fuel in the furnace and below the nostril arch. If carbonic oxide is found at a point beyond this, it is certainly indicative of a shortage of secondary air. The Refractory Materials Committee are evidently satisfied that the reducing atmosphere test is not of sufficient importance to warrant the use of the comparatively complicated apparatus which it entails, for in their specification of retort material a test atmosphere of an oxidizing nature is specified.

The Retorts.

It is not within the power of the retort manufacturers to alter materially the chemical composition of the clay occurring in their districts; hence it is by modifi-

cation of the texture of the finished article and attention to the details of manufacture that greatly increased refractoriness has been obtained. Not only do the retorts have to withstand high heats, but in addition, as discharging and charging takes place, they are exposed to considerable fluctuations in temperature. Moreover, they must be of a certain mechanical or physical strength in order to carry the loads to which they are subjected and to resist the strains put upon them by modern stoking machinery. In the case of the full coal charge and "pusher," the retort has to withstand some considerable bursting pressure in the event of a charge jamming-up and refusing to move. For high temperature, a highly refractory material is required; and to obtain this, high porosity and a fairly open grain are essential. This is chiefly due to the fact that an open grain means larger individual particles, and the heat and flame have greater difficulty in penetrating to the interior of these than in the case of smaller dust-like particles. The main function of porosity, however, is that of imparting to the material the ability to withstand fluctuation in temperature. For mechanical strength, on the other hand, a close-grained material of high density gives the best results, whilst diffusion of coal gas outwards or furnace gas inwards through the walls of the retorts is more effectively restricted, and better thermal conductivity is obtained. In the manufacture of the retort, therefore, these contrary requirements have to be reconciled as far as possible, although greater attention is usually paid to refractoriness. It is in this way that porosity plays so important a part; and no doubt the success of the German-made retort (which even now has a higher porosity than the specified English type) can, in all probability, be greatly attributed to this fact. Porosity, however, as will be realized, is a somewhat dangerous property to interfere with, unless considerable care is exercised to keep it within the prescribed limits. It cannot be denied that any increase in porosity may be accompanied by a corresponding decrease in the capacity of the material to withstand working stresses; hence too much zeal in the open-grain doctrine is likely to tell somewhat seriously when the working life of a retort comes to be reckoned up. Evidence of this is seen in a certain number of retorts having a porosity up to as much as 30 per cent. which at one time found their way into gasworks with decidedly unhappy results. In this connexion it is particularly interesting to note that, whilst the Refractory Materials Committee specify a minimum porosity of 18 per cent., the German-made retort has an average in the neighbourhood of 25 per cent. It has been shown, too, that in this country the German retorts, with due care, are capable of surviving about 2,100 days. A comparison between working life and porosity in this way is striking, in that it shows that even with a comparatively open texture a high degree of mechanical strength is obtainable. A rather puzzling fact, however, is that, judging from appearance, the German material gives an impression of lower porosity than the English specification type. (*See* Figs. 78 and 79.) The open grain shown in Fig. 78 gives a very good indication of the manner in which increased refractoriness over the original material (Fig. 80) has been obtained. With regard to conductivity, it has been shown that if an ordinary fireclay retort is burnt at 1,900° Fahr., and the final substance is taken as giving a standard coefficient of conductivity (*i.e.*, 1), the figure will be in-

creased to 1·6 if burning takes place at 2,350° Fahr. It is for this reason that a retort will give a greater conductivity after having been in use for some time.

The practice of coating the inner surfaces of the retort with a glaze, which is prevalent in Germany, has never gained much favour here, although in the Williamson-Cliff new type of retort this is done. The glaze is primarily intended to act as an impervious coating to prevent diffusion of gas through the retort walls. The friction of the stoking machinery disposes of the greater part of it; but by this time "scurf" will have formed, and will take up the duty of the glaze. Experiments have recently been conducted in connexion with the problem of the outward

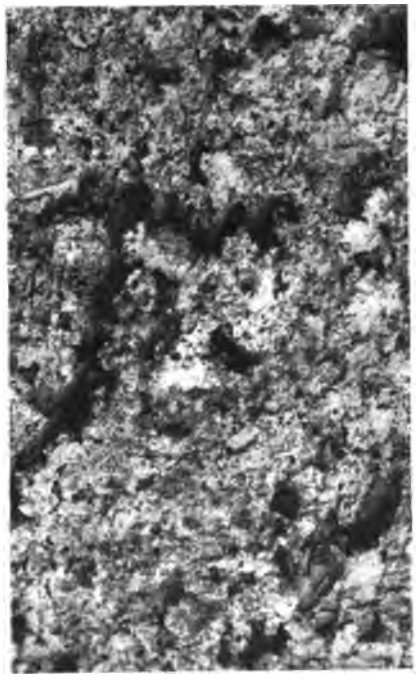


FIG. 78.—SECTION OF STANDARD SPECIFICATION MATERIAL.

FIG. 79.—SECTION OF TYPICAL GERMAN RETORT MATERIAL.

diffusion of gas through the retort walls during the early stages of the charge, when the retorts may be subjected to some pressure, and it is a question whether the increased porosity of the material is not an offender in this direction. When perfectly new retorts are in use, there is little doubt that some gas must be lost in this way, although the formation of "scurf"—a fairly speedy operation—will soon act as a check. The effect of carbon in sealing up the interstices of the retort walls is well illustrated by the photograph shown in Fig. 84. When demolishing old retort benches, it is very usual to find a black stripe running completely round the section of the retort. The stripe, commencing about a quarter of an inch from the inner surface of the material, will usually run to about an inch in width, and is plainly

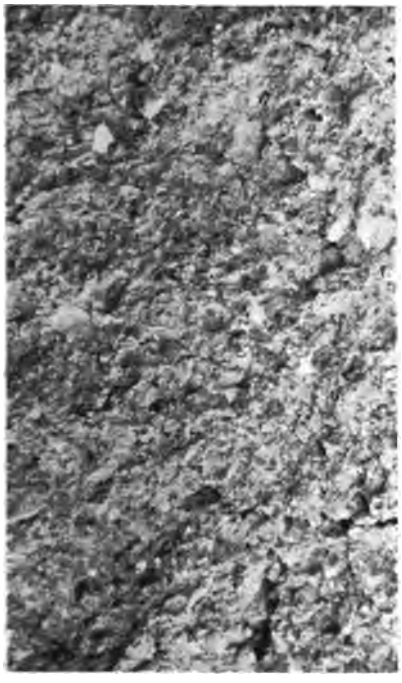


FIG. 80.—SECTION OF ORIGINAL RETORT. MATERIAL.

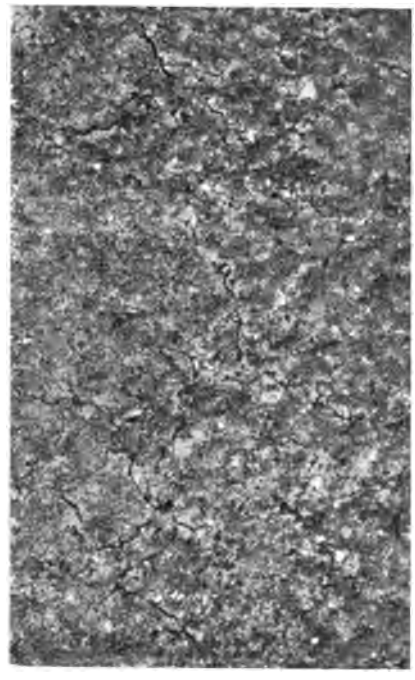


FIG. 81.—EXTERIOR SURFACE OF ORIGINAL MATERIAL.

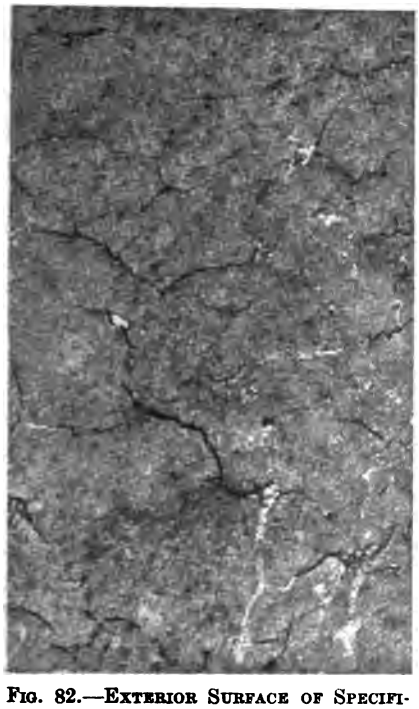


FIG. 82.—EXTERIOR SURFACE OF SPECIFICATION MATERIAL.

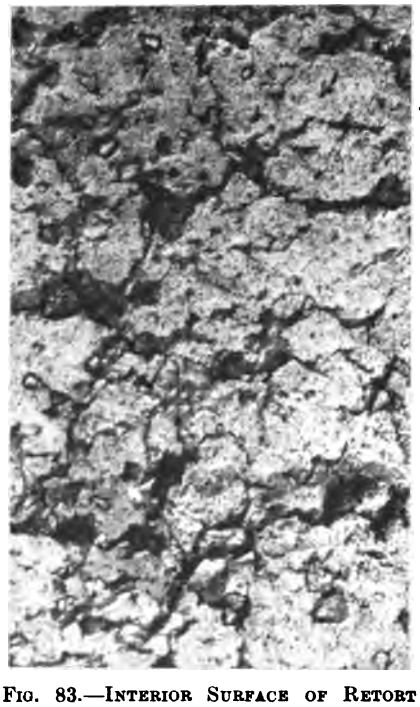


FIG. 83.—INTERIOR SURFACE OF RETORT AFTER 500 WORKING DAYS.

seen in Fig. 84. It is somewhat puzzling to know why this "carbonized" layer should be sandwiched in the material in this way. The explanation would appear to be that the inner deposits are burned out with the inrush of air as the retort doors are opened for charging or "scurfing." An analysis of the black layer has shown that, on an average, it contains 10 per cent. of free carbon.

Retorts in this country are made by two distinct methods, *i.e.*, hand-moulding and machine-pressed. The former method is still employed in many yards to-day, and consists in plastering the clay to a certain thickness round a "plug" of the required shape. The whole length of the retort is not plastered on in one operation, but is formed in stages of about 18 inches to 2 feet in length at a time. The mandril is placed in a vertical position, and after the first stage has been moulded it is permitted to stand aside for a day or two until sufficiently dry to bear the weight of the next stage. In some instances, chiefly on the Continent, a different method is used. An outer casing is fitted with a core so as to form an annular space corresponding to the shape of the retort. The clay substance is then rammed into the space by means of long-handled punners provided with spiked ends. The object of the spikes is to release air bubbles which would affect the porosity of the finished article.

FIG. 84.—SECTION OF USED RETORT SHOWING CARBON LAYER.

Machine presses for retort making (Fig. 85) are chiefly operated by steam power, and consist of a large cast-iron cylinder in which the piston or "press-head" works. The cylinder is filled up with a certain quantity of clay, depending upon the capacity of the machine, and as the piston goes down the clay is compressed and forced through a die at the base of the cylinder. The die is fashioned in accordance with the shape of the retort required, and as the moulded clay passes through, it is supported by a movable table, which descends at the same rate as the compressing cylinder. The moulded retort issuing from the die and resting on the movable table is shown in Fig. 86. Machines of this description are capable of making 400 to 500 feet of retort per day.

THE QUALITIES OF HAND-MADE AND MACHINE-PRESSED RETORTS

With regard to manufacturing costs, there is little to choose between the two types of retort, but from the point of view of working life the hand-made article

is usually to be preferred. The fact that the machine type is made in a single operation may account for somewhat greater homogeneity, but the gradual building up in distinct lifts ensures slower drying, which is desirable. Machine-made retorts are denser and heavier, but an excess of density can be avoided by the addition of sawdust or coarser grogram. Owing to the high working pressure of the machines the prepared clay must of necessity be stiff, otherwise warping and sagging will occur after the material has passed the die. Stiff material put together by pressure

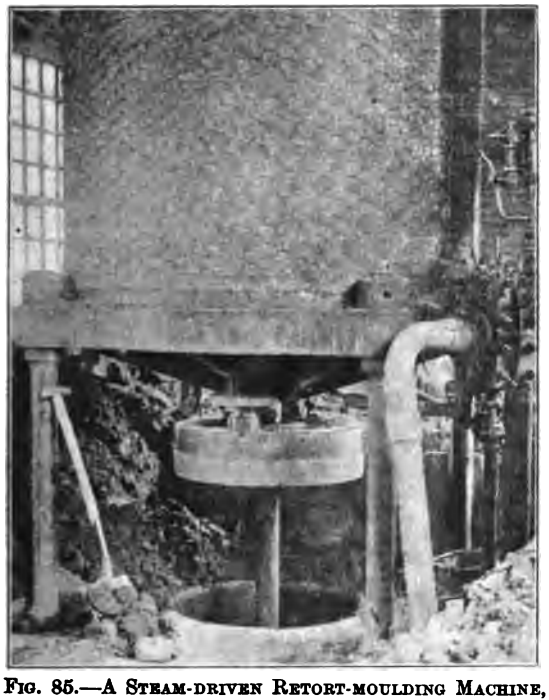


FIG. 85.—A STEAM-DRIVEN RETORT-MOULDING MACHINE, SHOWING LOWER PORTION OF STEAM CYLINDER AND UPPER PART OF CLAY CYLINDER, THE LATTER WITH PISTON UP SO THAT IT MAY BE CHARGED WITH CLAY.

FIG. 86.—RETORT PASSING THROUGH MOULDING DIE.

is not so effective for most purposes—particularly retort work—as a more plastic clay which is put together by hand. When the clay is plastic, the additional amount of water is afforded an opportunity of carrying out its function of knitting and binding up the particles. Moreover, when the ram under heavy pressure squeezes or drives the clay out of a retort machine, there is a tendency to destroy the best setting of the grog and to drive the coarse particle into a more or less regular formation. On the other hand, the machine-made retort, prepared with due care, is far cleaner, more regular and straighter than that made in successive lifts by hand.

SEGMENTAL RETORTS

From the point of view of working life, segmental or built-up retorts are far superior to the common moulded type, but, chiefly owing to the preliminary expense

incurred, they have not been very generally adopted in this country. Built-up retorts may be classified under two headings, namely, those composed of large segments and those constructed from special small blocks about the size of an ordinary brick. It has been said that retorts built up from small tongued and grooved segments can be worked continuously for five years without requiring repairs, the explanation being that the flexible units give and take with the expansion and contraction caused by the variation of temperature in the setting. In the case of a brick retort, the line of fracture necessarily follows along the joint-lines, whereas in the case of a moulded retort the line of cleavage is indefinite, and cross-stresses are set up. Under local heating, it is impossible to expect perfectly uniform movement; thus, when the retort is composed of one single piece, cracks and fissures result. In these days of the "pusher," moreover, distortion must be avoided if the charge is not to jam up. In this respect, the built-up retorts composed of small units are probably to be preferred to those in which large sections are employed, although opinion in this respect differs considerably.

The retort built up of small units is extremely flexible, and yet (owing to the tongued and grooved joint) little or no leakage takes place. A difficulty, however, arises when "scurfing" is considered, for, owing to their delicate adjustment, the separate units are liable to be damaged with the heavy tool employed and the rough handling they receive. Furthermore, there is the possibility of the carbon getting into the joints and opening out the bricks in this way. Segmental retorts require, of course, substantial and at the same time flexible supports, this being another factor which adds to the expense. With regard to the relative "gas-tightness" of the two types of retort, there appears to be some divergence of opinions. It may be generally taken, however, that, so long as the segments are carefully made and laid together, the gas leakage will, in the long run, be less than with the moulded retort, in spite of the number of joints necessitated. Some authorities attribute the tightness of the segmental retort to the fact that when a line of cleavage occurs, it runs along the joints and is quickly sealed by the formation of scurf. With the moulded retort, on the other hand, the cracks may be anything from $\frac{1}{8}$ inch to 1 inch, or even greater. The built-up retort, moreover, lends itself to effective repair. Bywater has stated that for horizontal retorts the use of the segmental principle, although heavier in initial cost, results in a saving of more than 1*d.* per ton of coal carbonized during their life.

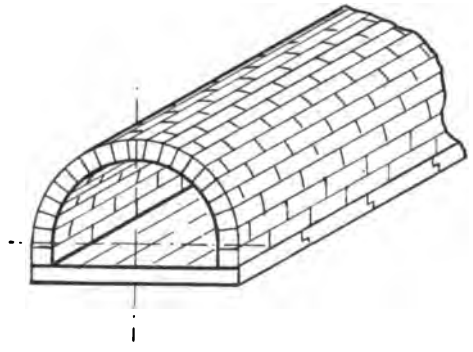


FIG. 87.—BRICK RETORT WITH TILED BASE.

A typical brick-built retort with tiled bottom, of a somewhat old-fashioned type, is shown in Fig. 87, whilst the more common forms of segmented retorts are illustrated in Fig. 88. In all cases where the latter types are used the modern tendency is to

employ a highly refractory material of a silica nature (such as the Oughtibridge or Bonnybridge types); but experience has shown that this clay is of little avail in withstanding the erosion caused by friction of the coke. Accordingly, while the arch of the retort is composed of silica material, the shoulders and base are made from an aluminous clay of a Stourbridge nature, as shown in Fig. 89. With occasional repairs, retorts of this description have, in some instances, recorded a working life of 3,000 days. Some idea of the longevity of the segmental chamber retort may be gathered from the fact that the ovens employed in the Munich chamber installations have, in many cases, been in use for nine consecutive years.

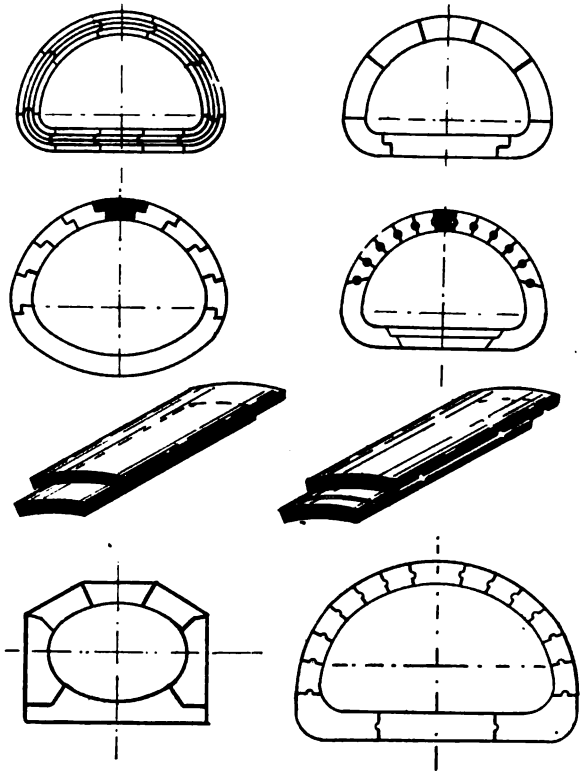


FIG. 88.—TYPES OF BUILT-UP RETORTS.

To overcome the inability of the silica ware to withstand friction, A. Cliff has suggested the adoption of a composite retort as shown in Fig. 90.

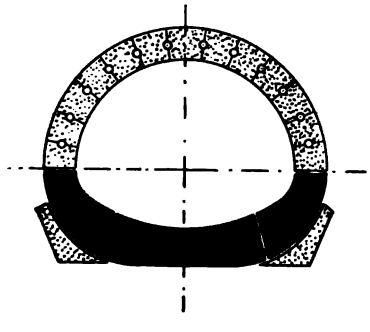


FIG. 89.—SEGMENTAL RETORT WITH SILICA ARCH AND ALUMINOUS BASE.

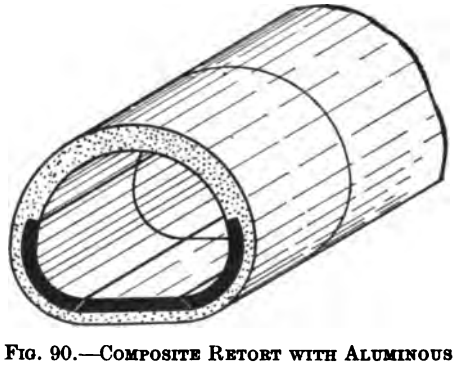


FIG. 90.—COMPOSITE RETORT WITH ALUMINOUS BOTTOM.

In some instances the segments composing a rebated retort are carried right up to both ends, and cast-iron sheaths (similar to that shown in Fig. 102, p. 157) are

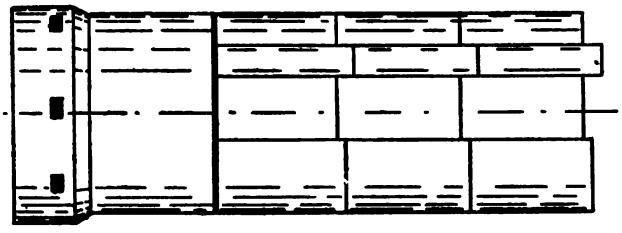


FIG. 91.—SEGMENTAL RETORT WITH MOULDED MOUTHPIECES.

used for attaching the mouthpiece. The more modern and satisfactory method, however, is to form the last couple of feet from a short length of moulded retort as seen in Fig. 91. This is, as in the ordinary way, composed of Stourbridge clay, which possesses the advantage that it is not injured by the condensed alkaline vapour falling back from the ascension pipe. Silica material, on the other hand, is quickly reduced to a powder in this way.

THE CORROSION OF RETORTS

A contingency of no little concern to the coke-oven engineer, but fortunately occasioning but small anxiety in connexion with gasworks' retorts, is the damage caused to fireclay by saline corrosion. All coals contain a certain amount of sodium chloride, and apparently when this is decomposed the basic salt of sodium combines with the surface of the retorts or bricks, thus forming an injurious coating on the interior. This coating, being sensitive to the variations of temperature, cracks and opens, so that further quantities of the harmful fumes can enter, and in time the retort becomes covered with a crumbling substance of low-fusing point. In the affected portions the proportion of silica may be reduced by so much as 6 per cent., while the injurious alkaline impurities are increased by over 3 per cent., this greatly aggravating the tendency of the material to "run." Fortunately, the majority of gas coals in general use contain only small quantities of sodium chloride, and thus the effect is not particularly marked. At many coke-oven plants, however, the chamber walls have to be replaced in less than twelve months, owing to the action of the salt, and this in spite of the fact that the coals are almost without exception washed before use, as there is a certain proportion of the salt so closely incorporated with the coal that the ordinary washing methods are ineffective in removing it. Observations made at a coke-oven works showed that a proportion of 0·143 per cent. of salt in the water employed for washing coals ruins a retort in three years, while one-quarter of this amount renders a refractory substance of little value after five years' work.

THE COST OF RETORTS

At the present time, prices for retorts must be given with caution, as there are somewhat obvious indications that, with the stipulations applied to manufacture and the better quality of articles turned out, the figures are unlikely to remain stationary. At the same time, much depends upon the locality, also the size of the works, the larger works with big demands naturally being supplied at a lower figure than a smaller concern requiring an identical article. Taking London delivery as an average instance, however, the following figures may be given :—

Standard specification retorts	5*s*. 9*d*. to 6*s*. 6*d*.	per foot run,	delivered.
Good quality (not to specification)	4*s*. 8*d*. to 5*s*. 2*d*.	,,	,,
German retorts	7*s*. to 8*s*.	,,	,,
Segmental retorts:			
1. All aluminous material	6*s*. 6*d*. to 7*s*. 3*d*.	,,	,,
2. Silica tops, aluminous base	7*s*. 9*d*. to 8*s*.	,,	,,

These prices are all for average sizes. The very large patterns would be slightly more costly, whilst very small sizes would be rather less. Special shapes are, of course, extra.

With regard to the actual laying of segmental retorts, an additional cost (compared with moulded types) of from 9*d*. to 1*s*. per foot should be allowed.

SILICA RETORTS

Retorts made entirely from silica material, although little beyond the experimental stage, have been used to some extent in the gasworks of America. Silica material, *per se*, has no binding properties, and the clay made use of (containing about 95 per cent. of silica) is moulded by the introduction of about 2 per cent. of some binding substance, such as lime. The finished articles are extremely fragile, and require great attention during heating-up if cracks and fissures are to be avoided. Furthermore, it seems that they are not capable of standing any considerable loading when under heat. In all instances, with the exception of concentric rings used in vertical retort systems, the silica retorts so far made use of have been of the segmented pattern, although in some cases a moulded aluminous end is used, as previously described. Owing to the somewhat excessive expansion of this type of material—amounting to as much as 1½ per cent. of its original length—great attention has to be given to the setting of the segments, and joints are in some cases made with thin cardboard, which eventually burns away, making room for the increase in length. Another compensating method is to make moderately thick joints of an aluminous clay, which, on heating-up, contracts and makes way for the expansion of the silica. According to investigations carried out by the Refractory Materials Committee of the Institution of Gas Engineers, the life of silica retorts, when used in conjunction with stoking machinery, is from 3½ to 4 years. One of the chief merits of the silica material is its proclivity, owing to a much denser grain, to transmit heat far more readily than is the case with articles made from the ordinary mixture of aluminous clay and grog. Owing to this fact a certain saving of fuel can be looked for, although the chief advantage lies in the increased carbonizing capacity of the retorts. That is to say, more coal is capable of being dealt with in a definite period owing to the possibility of burning-off the charge much more rapidly. Silica material should on no account be exposed to the action of the weather.

PROTECTION FOR RETORTS

Owing to the expansion of the siliceous material employed in the cross-walls and other portions of the setting, the retorts often suffer damage from the increased stresses put upon them. A method for overcoming this effect, which has been

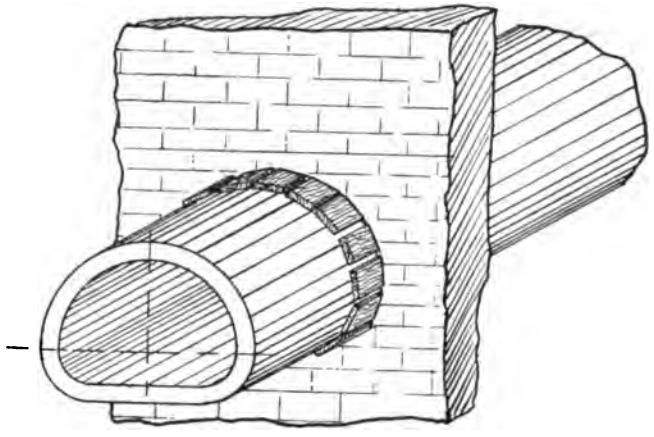


FIG. 92.—THE WOODEN STRIP IDEA.

employed with some considerable success, is that shown in Fig. 92. The idea, as will be seen from the sketch, consists in placing a shuttering of wooden strips completely around the sides and top of the retort, the strips being built into each cross-wall as it goes up. As the temperature of the setting is gradually raised, the wood chars, and finally burns completely away when the working heats are obtained, thus providing a small space for expansion, and preventing undue pressure on the retort. Owing to the liability of retorts immediately surrounding the combustion chamber to suffer from the severe and sometimes local heating at this point, it has for some time been the practice to insert special silica protection shields (as shown in Fig. 93) around the bottom corners. At the same time the silica material is liable to be affected by the slagging action of the dust carried forward by the furnace gases; and, for this reason, the block illustrated in Fig. 94 has in some cases been adopted. This shield is made wholly from Stourbridge clay, of the same material as the retorts, and will frequently be found to outlast the retorts themselves. The main body of the block is 3 inches in thickness, and it is made of such a length as to run from centre to centre of the cross division walls from which it is supported.

Another successful idea, which has been introduced with a view both to economy and the protection of the retort, is that shown in Fig. 95.

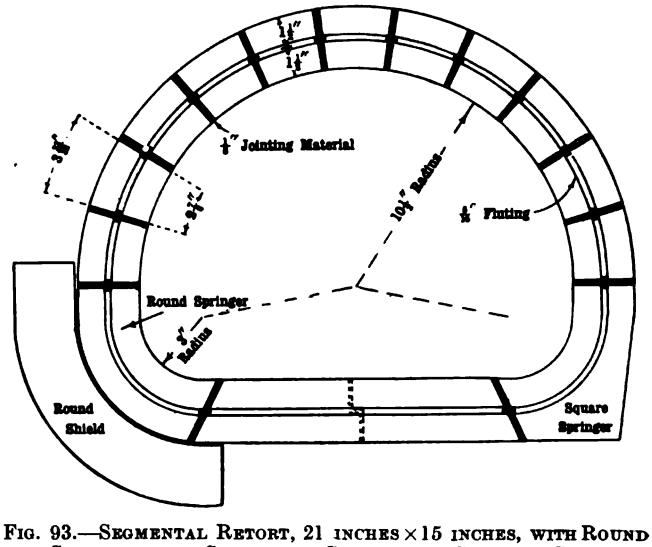


FIG. 93.—SEGMENTAL RETORT, 21 INCHES × 15 INCHES, WITH ROUND SPRINGER AND SHIELD ON COMBUSTION CHAMBER, SIDE AND SQUARE SPRINGER ON EXTERNAL SIDE. THE LENGTH OF THE SEGMENTS VARIES FROM 1 FOOT 3 INCHES TO 2 FEET.

In the majority of cases of "through" retort settings it is customary to insert a 9-inch cross-wall here and there in the setting, and particularly where the retort joints occur. By adopting the arrangement shown in the sketch, the expense of the heavier wall is obviated, and 4½-inch brickwork (or certainly 6-inch) can be run up instead. A 9-inch ring of brickwork (usually Ewell) is carried completely round the retort, and the 4½-inch wall carried direct from this. In the case of those retorts surrounding the combustion chamber, the brickwork makes an admirable substitute for special protection blocks.

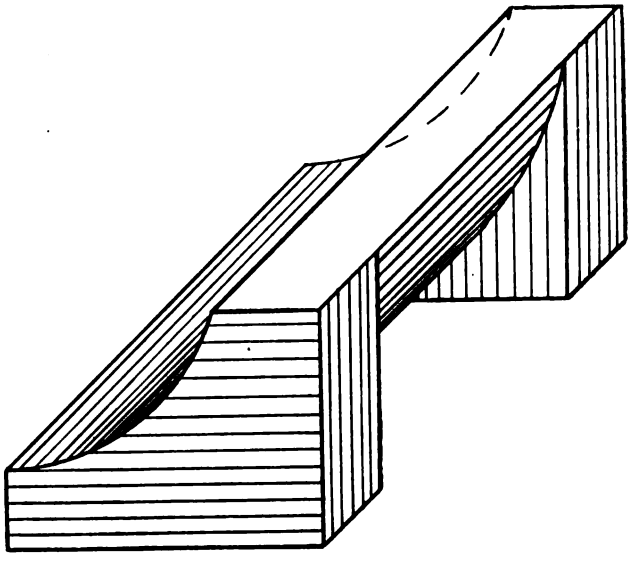


FIG. 94.—FIRECLAY SHIELD BLOCK.

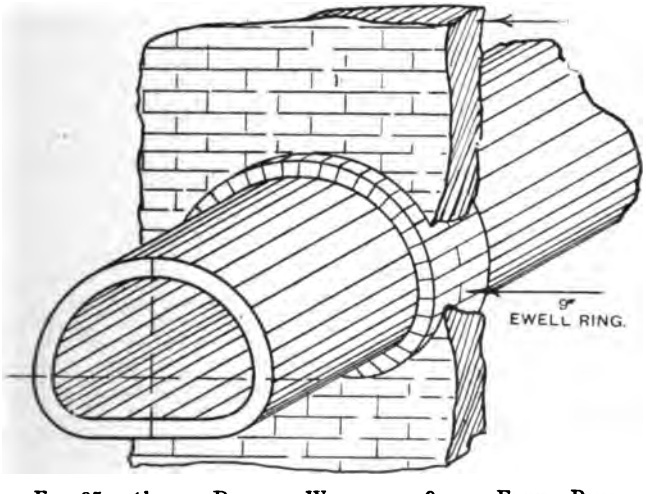


FIG. 95.—4½-INCH DIVISION WALL WITH 9-INCH EWELL RING.

COMBUSTION CHAMBER AND CROSS-WALLS

The greatest intensity of heat which is produced in a retort setting is in the combustion chamber and its immediate neighbourhood; hence a material of high refractory qualities is essential. In this respect the siliceous or silica materials are to be preferred, and those of the Dinas type, containing upwards of 96 per cent. of silica, are now coming into fairly general use for the purpose. In this connexion it is always well to bear in mind that while fireclay of the aluminous or Stourbridge type shows some tendency to contract when under working heats, the clays known as siliceous invariably expand; and, as a general rule, the higher the silica content the greater will this tendency be. Bricks of the

Ewell type, however, being intermediate so far as silica content is concerned (87 to 89 per cent.), remain practically stationary, although at the more intense heats there may be some slight tendency towards expansion. Owing to this property, also to their high refractoriness, the Ewell bricks are largely used for combustion chambers and cross walls in modern settings.

The characteristic of certain bricks to diminish or increase in size is rather liable to upset the calculations of those responsible for the design of settings, one of the chief consequences being that the retorts, after a short time, fall slightly out of level. In order to avoid this, an arrangement has been introduced by some engineers whereby the varying properties of the two types of material are made to neutralize one another. For instance, the furnace arch and combustion chamber may be built up of silica ware and the division walls of material having a contracting nature. On heating up, the expansion of the former is counteracted by the contraction of the latter—hence everything is maintained on an even keel. A setting built up in this way is diagrammatically shown in Fig. 96.

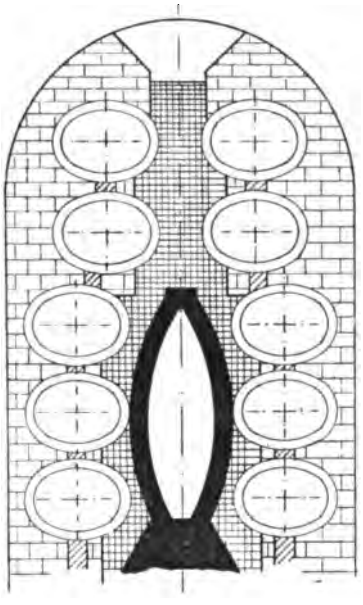


FIG. 96.—COMPENSATION ARRANGEMENT FOR EXPANSION AND CONTRACTION.

Attention must be drawn to the practice of running up the cross-walls between the retorts and above the combustion arch of siliceous material, while on the outer side of the setting, where the heat is less, the same walls are continued in aluminous work. In such cases it is frequently found that the retorts tend to overturn in an outward direction (particularly if the joints in the wall have been made fine), this being due to the pushing upwards and outwards of the silica material, whereas the aluminous material on the outside will have undergone a certain amount of shrinkage, thus allowing the movement to take place. In the construction of all types of division walls, it will be found an excellent policy to leave a big joint here and there to take up the crowding out, if necessary. With regard to these cross-walls, it must be remembered that, so far as the greater portion of them is concerned, mechanical strength is desirable rather than extreme refractoriness, for the material merely comes in contact with the circulating gases, and is not likely to be affected by any severe cutting heat. Consequently, a brick of greater density and less porosity may be used, and ordinary Stourbridge fire-bricks of the best quality usually give every satisfaction. Speaking of "cutting heats," it is as well to point out that small combustion chambers, although they have their advocates, are decidedly conducive to these, and also prevent the effective mixing of the gases.

Bywater has drawn attention to the necessity of employing bricks for the cross-walls which are of sufficient refractoriness to withstand the working temperature, as drippings resulting from the fusion, or partial fusion, of these often cause trouble. He further recommends the use of high-class bricks of the Glenboig, Ganister, Stourbridge, or Yorkshire and Derbyshire biscuit silica as being quite suitable and desirable.

The disastrous effect which a small proportion of alkaline impurities may have on the remainder of the setting has already been emphasized. It is well known, of course, that in the case of the ordinary stock building brick the original clay contains a comparatively high proportion of impurities, and these are actually caused to flux during burning so as to firmly bind the remainder of the material together. A point to remember is that extremely high temperatures and "cutting heats" are not alone responsible for "running." Considerable damage from

FIG. 97.—THE EFFECTS OF "RUNNING."

this cause may often be found at the relatively cool zone of the producer linings, and also at the base of water-gas generators. Such occurrences are, of course, due to the adhesion of clinker (having an extremely low fusion point) to the walls, and its subsequent "slagging" action on the impurities of the lining material. The chief precaution is to ensure that the bricks or blocks made use of contain a low proportion of fusible constituents. The unwelcome results of "running" are very well illustrated in Fig. 97. This photograph shows the consequences of using an unsuitable jointing material, and the manner in which incipient slagging has been set up in the brick can be clearly noticed. The brick in this case was taken from a combustion chamber working at a temperature of about 2,600° Fahr.

With regard to fireclays for the making of cement for use in retort benches, before making a definite purchase it is advisable to apply a rough test in order to ascertain their suitability. An excellent rough method for determining their refractoriness

is to mix up the cement in the usual way, afterwards plastering it on one side of a brick to the depth of about an inch. The brick should then be pushed into the combustion chamber of a retort setting and allowed to remain for about a week. If at the end of that time there is no sign of fusion, the material may be safely relied on. The test is, no doubt, severe—particularly in view of the rapid rate at which the temperature of the sample is increased.

PRQDUCERS AND REGENERATORS

As pointed out above, the material employed for the lining of the producer must possess the ability to withstand the slagging action of the low fusing-point impurities associated with the fuel. It is a recognized rule of retort-house practice that the furnaces must not be too hot; therefore there is theoretically no need for very high refractoriness. If, however, an inferior brick were made use of, the results would undoubtedly be very far from pleasing, for the heat in the producer —chiefly owing to fluctuation in the depth of the fuel bed—undergoes severe changes.

With regard to the construction of the regenerator flues for the circulation of secondary air and waste gases, it must be borne in mind that the arrangement is employed with a view to abstracting the maximum of heat from the waste gases and conducting it to the secondary air. Accordingly, as the heat to be withstood is comparatively low, the bricks or blocks should be made with an eye to high thermal conductivity and mechanical strength rather than to high refractoriness.

OUTSIDE WALLS AND INSULATION

The chief qualities required of the material of which the outside or front walls of the setting are composed are moderate refractoriness, but, more especially, a low ability to conduct heat. By far the most common practice is still that of building up these walls of 9-inch or 13½-inch work in aluminous fireclay, but within the last few years some attempt has been made to reduce the thermal losses by radiation from these walls to a minimum. Chief among these methods is that of building up a cavity wall (a clear 2-inch space usually being left, whilst for the sake of stability the two walls are tied together at intervals by a brick), the cavity being left clear, or filled in with some type of non-conducting material, such as asbestos composition. A more recent means is to fill in the cavity or to build up a separate interior wall from one of the special types of insulating bricks, such as the "Thermalite" or "Moler." These bricks are extremely light, thus indicating high porosity and low conductivity. On the Continent, a practice is in vogue by which the entire outside wall is constructed of large hollow blocks as shown in Fig. 98. In the case where a screening wall of some type of insulating material is employed, there seems little reason why the face wall of the setting should not be built up entirely from ordinary stock brickwork. Such

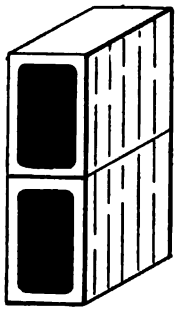


FIG. 98.—SPECIAL AIR-BLOCKS FOR OUTSIDE WALL OF SETTING.

bricks, owing to their relatively high porosity, would ensure the retention of a further amount of heat.

APPROXIMATE MELTING POINTS OF VARIOUS SUBSTANCES

Chromite	3,950°	Fahr.
Magnesia brick	3,930°	,,
Chromite brick	3,722°	,,
Pure alumina	3,650°	,,
Bauxite clay	3,260°	,,
Pure silica	3,200°	,,
Kaolin	3,160°	,,
Silica brick	3,090°	,,
Fireclay brick	2,900°	,,

CHAPTER VII

RETORT-BENCH APPURTENANCES

THE retort-bench fittings employed with modern horizontal settings do not vary in character to any marked extent. Various engineers employ different means for arriving at the same end; but the distinction in most cases is generally a matter of detail. In the first place, the chief items requiring consideration are :—

1. (*a*) The primary staying-up of the bench (*i.e.*, by longitudinal and transverse buckstays and ties).
   (*b*) The secondary staying-up of the individual setting, such as cross-bracing between the buckstays to prevent protrusion of the regenerators and the producer front. Also the bracing of the front walls above the producer, and the retention and support of retort mouthpieces in their correct position.

2. In addition, consideration has to be given to the various features in the design and erection of the retort mouthpieces, ascension pipes, bridge pipes, hydraulic mains, etc., so that the process of gas making may proceed with the regularity essential to the best results.

RETORT MOUTHPIECES

The self-sealing metal-to-metal retort door is now in almost universal use, except in the smallest of works making less than about 6 to 8 million cubic feet of gas per annum, which, for the sake of convenience, still adhere to the detached door with spent lime luting and central-tightening hand-screw. For small stop-ended retorts this method is advisable, particularly in cases where no facilities exist for re-adjusting the self-acting type. As the means wherewith hermetical sealing is obtained in the common type of door are not always fully understood, a diagram (Fig. 99) is given showing the principle employed. First, the tightening handle is forged with two eccentrics, as shown in Fig. 100, and the cross-bar passing in front of the lid turns on these eccentrics. At the same time, when the tightening handle is turned it revolves about the centre of rotation shown. It is thus seen that the eccentrics force the cross-bar towards the lid, and the bar—turning on the fulcrum formed by the clip B—transmits pressure to the centre of the door at A. By means of an eccentric bolt, with which the cross-bar is attached to the rib of the door at A, wear can be taken up and the pressure regulated. With the Ω-shaped

door the pressure is not applied at the true centre, hence it is greater at certain portions of the faced rim than at others, this being an objectionable but unavoidable feature of the appliance.

The means employed for attaching the mouthpiece to the retort is of consider-

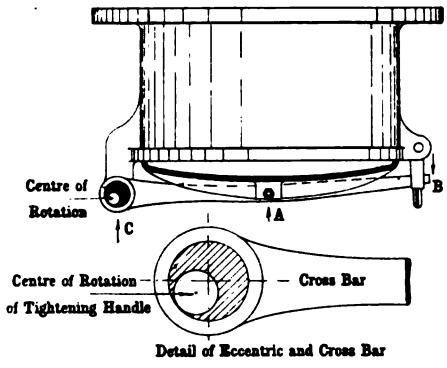


FIG. 99.—SELF-SEALING RETORT LID, SHOWING PRINCIPLE OF ACTION.

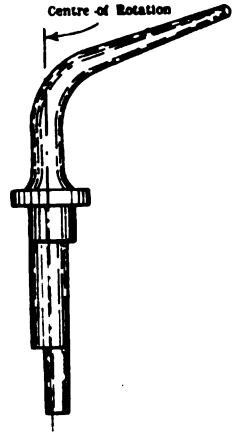


FIG. 100.—DETAIL OF TIGHTENING HANDLE, SHOWING ECCENTRICS.

able importance, as an insecure joint soon gives way under the stresses of the stoking machinery and pipe augering. There are three distinct methods now made use of for affixing the mouthpiece. The most common method (Fig. 101) is to cast the mouthpiece with a plain back flange, the flange being drilled at intervals for bolts, which are secured in slots in the thickened end of the retort. In this case some form of jointing material must be used between the flange and fireclay end of the retort, for which purpose the following usually gives the best results: One part of cast iron borings to 2½ parts of fireclay, the mixture being just damped with a solution of sal ammoniac. The amount of sal ammoniac required is about 1 lb. to every hundredweight of the fireclay and borings. For this purpose sal ammoniac is to be preferred to ammoniacal liquor, as a more complete rusting action is set up.

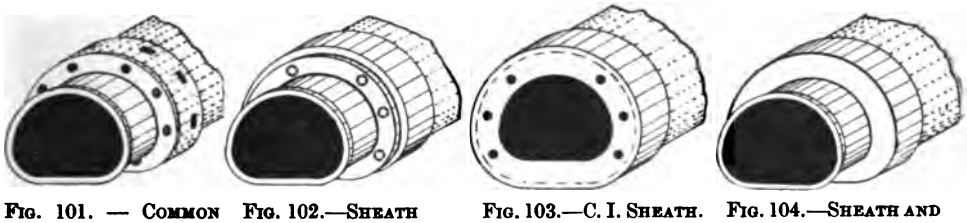


FIG. 101. — COMMON BOLT ATTACHMENT. FIG. 102.—SHEATH ATTACHMENT. FIG. 103.—C. I. SHEATH. FIG. 104.—SHEATH AND MOUTHPIECE COMBINED.

METHODS OF ATTACHING MOUTHPIECES TO RETORTS.

A comparatively recent method of attachment is that shown in Fig. 102, in which a distinct sheath or socket is employed. The socket (Fig. 103) is made from cast-iron, usually ¾ inch thick throughout, and is passed completely over the end of

the retort, extending about 8 inches backwards. In this case the end of the retort is not thickened up, the lengths as laid having 3-inch walls throughout; and as a fairly tight fit is arranged for (slight chipping of the fireclay end often being necessary), no rust joint is employed, but the retort is given a wash of fireclay before the socket is fitted. Bolts, countersunk on the inside of the socket, form the attachment for the ordinary mouthpiece flange. The chief merits of the method are that the retort mouthpiece can be easily removed for repairs, the holding bolts are far less liable to burn or break away than with the common type of attachment, and, if properly fitted, a tighter, and at the same time more elastic, joint is obtained.

The third method (Fig. 104) is comparatively rare in this country, but possesses the advantage that no retort bolts whatever are required. It is really another means of carrying out the socket principle described above, with the difference that some initial expense is saved by casting the socket and mouthpiece in one. Its disadvantage, however, lies in the fact that the security of the mouthpiece is entirely dependent upon the cross bracing employed (although the latter can be made more effective owing to the absence of protruding bolts) and the socket portion has a tendency to crack. Once such a crack develops it is difficult to prevent a certain amount of gas leakage when the retort is under pressure.

In addition to the bolt attachment, all retort mouthpieces must be stayed up by means of bracing attached to the main buckstays, and passing outside the front wall of the setting across the flanges of the mouthpieces. There are several means of attaching such bracing, the most common being shown in Figs. 105 and 106. In

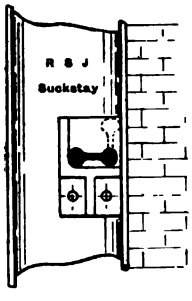


FIG. 105.—C. I. BRACKET FOR SUPPORTING BRACING RAIL FOR RETORT MOUTHPIECES.

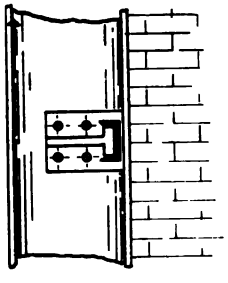


FIG. 106.—C. I. BRACKET FOR CHANNEL IRON MOUTHPIECE BRACING.

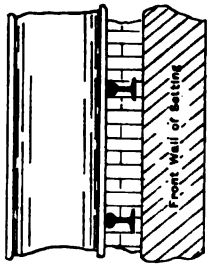


FIG. 107. — SINGLE BULL-HEAD RAIL SUPPORT.

Fig. 105 a double bull-headed rail is carried in cast-iron brackets attached to the buckstays as shown. In many cases the rail is carried across vertically (as shown dotted), so that an ample bearing on the lower portion of the flange of one mouthpiece and the upper portion of the flange of the mouthpiece just below may be obtained. The arrangement given in Fig. 107, although frequently seen, is not to be recommended, particularly in view of the fact that the main buckstays do not bear direct upon the brickwork of the bench, an intervening space being left which is filled in with a false wall.

ASCENSION PIPES, BRIDGE PIPES, AND DIP PIPES

The point of chief importance with regard to the ascension pipe is, perhaps, its size. Present-day practice in this respect is towards ample area, so much so that in many cases the pipes in modern installations provide practically double the cross-sectional area considered sufficient a decade ago. In general, however, design may be considered on safe lines if carried out in accordance with the following :—

SIZE OF ASCENSION PIPES

Works making under 10 million cubic feet per anoum . . .	5-inch pipe.
Works making between 10 million and 200 millioncubic feet per annum	6 „ „
Works making above 200 million cubic feet per annum . . .	7 „ „

This rule refers, of course, to retorts having an ascension pipe at each end, in the case of " through " settings. In a recent horizontal bench, ascension pipes of 8-inch diameter have been fitted at each end of the retort. The chief difficulty with the larger pipes lies in inducing the attendants to clear them properly. For 7-inch pipes a 5½ or 6-inch auger is generally used, but above this size the augers become somewhat unwieldy and difficult to handle, so that there is some temptation to make use of them as little as possible. In the arrangement of ascension pipes it is necessary to keep them as far as possible from the centre of the setting, so that they are unaffected by the heat of the combustion chamber. There is also the question of curvature, for the purpose of working round the upper mouthpieces. All abrupt bends must be rigidly avoided, otherwise endless trouble in cleaning the pipes and in the prevention of stoppage will ensue. Further, precaution must be taken to see that the jointing material used in the pipe sockets is not allowed to get past the spigot end, and thus be responsible for projections which partly stop the pipe and provide a lodgment for the formation of pitchy deposits. So far as the general arrangement is concerned, as many of the pipes as conveniently possible should be carried up on the sides of the main arch nearest its springings, and it is necessary to avoid running up two pipes between any two mouthpieces, otherwise the retorts will have to be spaced wider apart in order to give sufficient room, this tending to spoil the heating arrangements of the interior.

The joints in ascension pipes must on no account be made with lead. Although rust joints of iron borings are not essential, they are to be preferred to any other material, in spite of the additional labour entailed in cutting them out during dismantling. For ascension-pipe, bridge-pipe, and dip-pipe joints the following material may be used :—

Cast-iron borings damped down with gas liquor, rammed well into the joint, and left. When the bench is got to work, the heat from the setting quickly hardens off the joint.

Where borings are only obtained with difficulty, or to save expense, a very serviceable joint can be made from the following mixture :—

Ewell brick dust	1 part.
Slaked lime	2 parts.

This is rammed into the joint dry, no moistening whatever (beyond the slaking

of the lime) being necessary. In cases where a cast-iron foul main is used, lead joints may safely be used in the sockets, and are desirable.

STOPPED PIPES

The introduction into the larger works of the mass system of carbonization has proved the most effective deterrent to the old-time trouble of continually stopped ascension pipes. The absence of pitchy deposits may be chiefly attributed to the lower temperature of the escaping gases and the increased velocity with which they travel through the pipe. In addition, the elimination of an excessive "free space" in the retort accounts for less degradation of the hydrocarbons, with the result that a minimum quantity of free carbon is carried forward in suspension by the gas. It is such solid particles (also those drawn up from the cloud of coal dust inseparable from some types of charging machines) which, by adhering to the tarry surfaces of the interior of the pipe, promote obstruction. Once started, such obstruction grows apace.

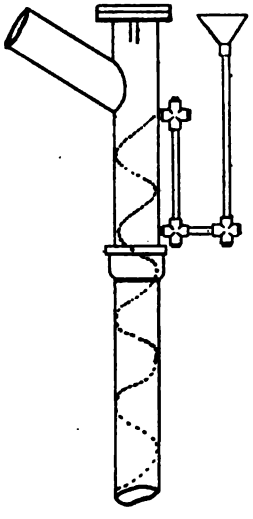


FIG. 108. — WATER-FEED FOR ASCENSION PIPE.

When the temperature of the issuing gases is high—such as with light charges or layer carbonization—the escaping tarry vapours undergo distillation and redistillation in the pipe until a pitchy mass capable of no further volatilization remains. The most satisfactory means to avoid stoppage is to ensure that every pipe is augered each time the retort is opened for charging, whether there is any apparent obstruction or not. Some engineers prefer to arrange for an auger gang to pass right through a definite row of pipes an hour or so before the charges are withdrawn. In this way the work of charging and drawing is not delayed, and it is claimed that the time is favourable for the operation owing to the condition of the tarry mass.

Many ideas have been introduced with the object of avoiding trouble from stopped pipes, and one of the foremost of these was the admission of a small trickle of water to the apex of the ascension pipe by means of a gooseneck (Fig. 108), or by the Darwen pipe (Fig. 109). In this way the temperature of the pipe is lowered, whilst the steam produced aids in carrying away a portion of the tarry vapours before their distillation can take place. Another means of arriving at the same result is to add a small proportion of water to the coals before carbonization, but some considerable loss in gas "make" may follow such procedure. In some cases a small steam supply has been admitted direct to the base of the pipe, but its use appears to be attended with mixed

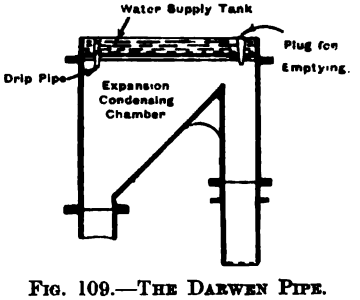


FIG. 109.—THE DARWEN PIPE.

results. A precaution, however, which calls for attention is the avoidance of cutting draughts around the pipes, and local cooling. Where the latter occurs in any degree, trouble will nearly always be experienced; and in some works provision has been made for ensuring uniform temperatures by jacketing the pipes with non-conducting material. This would certainly seem unnecessary in any but very exceptional cases; but care should be given in the design of the house so that draughts are avoided, whilst ample room should be left around the ascension pipes for the effective circulation of air.

THE SINGLE ASCENSION PIPE

In recent years there has been some tendency to work with only one ascension pipe for the removal of the gas from a through retort, instead of providing a pipe at each end, as is the more common practice. When the single pipe is used it should, for the standard sizes of through retorts, never be less than 8 inches in diameter. The following are the advantages which may be claimed for the single-pipe system :—

(*a*) Owing to the necessity of providing only one set of ascension pipes, dip pipes, hydraulic main, tar towers, foul main, etc., to each retort setting, the saving in initial cost is considerable. It must be remembered, however, that two hydraulic mains should be used when there are ten or more retorts to the setting, also with settings of " eight " in two rows. This is owing to the available width of the arch.

(*b*) There are fewer pipes to keep clear. At the same time the pipes are larger, and the labour, therefore, is more arduous. When the pipes are all on one side, the men can keep away from the stoking machinery, and are thus out of the way, whilst there is less liability of coal dust being carried up the pipe.

(*c*) There is said to be greater immunity from stopped pipes.

(*d*) There is said to be an improvement in gas yield and quality.

With regard to statements (*c*) and (*d*), they must be taken with a certain amount of reserve, as experience with single pipes has hardly been such as to definitely establish these facts. The disadvantages of the system are :—

(*a*) It cannot satisfactorily be employed when the retorts are fully charged, for although a vacuum may obtain in the end of the retort nearer the pipe, there is likely to be a heavy pressure at the other end, owing to the gas way being choked by swelling of the coal, uneven charging, etc.

(*b*) With light charges the gas travelling from the farther end of the retort is in contact with the hot walls for a considerably longer period than is the case when two pipes are employed. Hence excessive degradation is probable.

(*c*) If the single pipe becomes choked there is no alternative outlet for the gas; but, as previously noted, no well-managed works should have a completely choked pipe.

BRIDGE PIPES

The change of direction of flow of the gas from the ascension pipe to the dip pipe is effected by means of the bridge, arch, or saddle pipe. When direction has

to be altered in this manner a certain amount of friction is inevitable. The change must be effected as gradually and smoothly as possible, so as to avoid mechanical deposition of the tarry vapours and suspended particles. To this end sharp angles must be avoided. An equally important feature in connexion with the bridge pipe

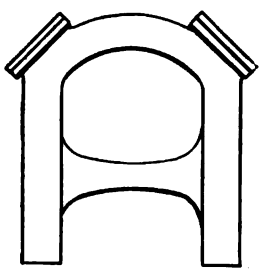


Fig. 110.

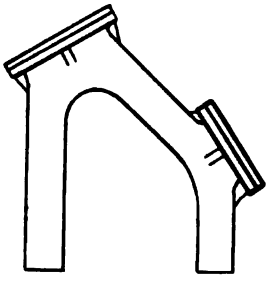


Fig. 111.

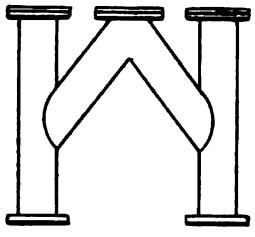


Fig. 112.

is that of ensuring easy access to all sections of the pipe way. Various types of bridge pipes are illustrated (Figs. 110 to 115). Fig. 110 is chiefly found in the smaller works. The design shown in Fig. 112 should be avoided, for, in spite of easy access to all sections, the change of direction is far too abrupt. The

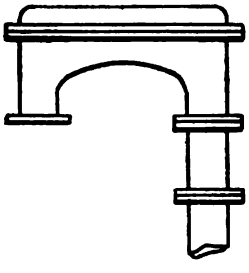


Fig. 113.

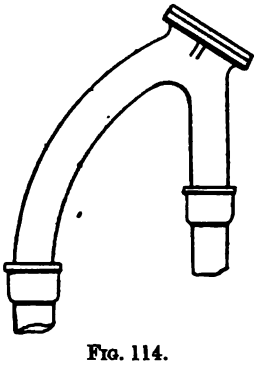


Fig. 114.
The Bournemouth Type.

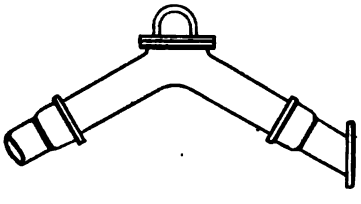


Fig. 115.
For Vertical Retorts.

"Bournemouth" type embraces many advantages, chief among these being the means of cleaning, both branches being accessible by the removal of a single flange, and that not a cumbersome one. The joints of bridge pipes should be made of similar material to that employed for ascension pipes. In the "Darwen" pipe (Fig. 109) a large expansion and cooling chamber is provided at the top of the ascension pipe, whilst the top of the bridge forms a water-supply tank which feeds a drip cock immediately above the rising pipe.

DIP PIPES

Dip pipes may be connected to the bridge pipe by means of either flange or socket joints; the latter are the more common. The pipe is always connected to the

hydraulic main by a flange. Although in many cases the seal end of the dip pipe is left square, it is now generally recognized that more effective working ensues if it is turned to a knife edge, as seen in Fig. 116. By this means less oscillation of the liquor takes place, the gas spreads more effectively, and suspended tar vesicles are more easily removed. For the last-named reason some engineers prefer the serrated end as in Fig. 117.

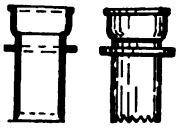


Fig. 116. Fig. 117.

Some care is necessary during the erection of dip pipes in order to ensure that the seal on each will be the same. Providing the hydraulic mains have been laid on a perfectly even keel, a uniform seal may be best obtained by machining a small portion of the upper face of the dip-pipe flange. When turning up the dip edges the distance (*d*), Fig. 116, can be made constant for all pipes. When the pipes are in position, ready to be permanently tightened down, a straight edge can be run along the turned portion of all flanges. So long as the straight edge remains level the dip pipes will then all be level at the lower edges, and any flanges not complying with the line of level can be there and then adjusted. This method is preferable to running a straight edge underneath the dips and inside the hydraulic main; and, if necessary, the dips throughout the whole house can be brought to a common level with ease.

When a retort bench is picked-up from cold, some means must be provided for permitting any slight movement of the ascension and bridge pipes. This may be allowed for by making one of the socket joints (preferably that where the bridge-pipe and dip-pipe meet) of slag wool to a depth of about 2 inches in the socket. This will permit movement; and when the heats are fully raised, the remainder of the joint may be made with borings in the usual way.

THE HYDRAULIC MAIN

Although there are still many cast-iron hydraulic mains in use, they are now never erected where renewals or extensions are carried out. Mild steel plates put together with the aid of angle sections are the modern practice, the plates being from $\frac{5}{16}$ inch to $\frac{7}{16}$ inch thick, the usual being $\frac{3}{8}$ inch. With regard to covers, cast-iron is still in many cases employed with the steel main, the reason being that owing to the numerous holes for dip pipes and bolts for flanges the steel cover is somewhat more costly, and is apt to spring unless stiffened. The steel hydraulic main is rarely made square in section, favourite designs being those of a ⊔-shape or with semi-circular bottom as at A in Fig. 118. From every point of view, however, the type shown in Fig. 119 may be looked upon as the most effectual. The base is given a decided fall to the tar outlet pipe connecting with the tar main or tower; and, in addition, the main is sloped longitudinally to the same pipe, so that in elevation it is V-shaped. One of the most important features is the apron plate, as seen, which permits of the thorough cleaning away of pitch or other deposits which may tend to block the tar-outlet pipe. A cock, as shown, should always be fitted to the tar pipe from each box, so that in the event of the cast-iron pipe breaking, the cocks may be shut and the unsealing of the dip pipes prevented. If a weir valve is em-

ployed, so that gas and liquor pass out of the box together, a tar shield, as shown in Fig. 120, should be attached to the front of the overflow. The heavier liquor and tar from towards the bottom of the hydraulic main will then flow away

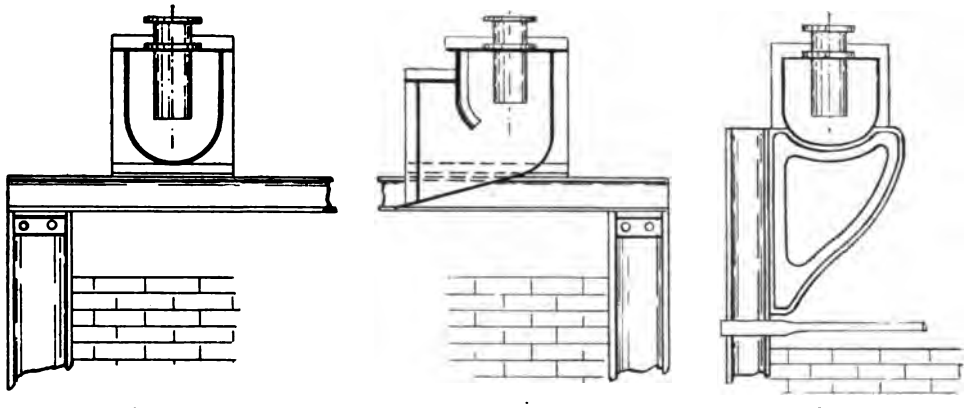


FIG. 118.—METHODS OF FIXING HYDRAULIC MAINS.

first. A Continental type of hydraulic main with weir valve is illustrated in Fig. 121. The main is provided with cleaning boxes fitted with automatic sealing devices having hand-wheel, screw, and locking bow. The special design of tar shield, in reality performing the duty of a tar box, will also be noticed.

Hydraulic mains as now erected are either :—

(*a*) Distinct mains, *i.e.*, one to every retort bench, on either or both sides ; or

(*b*) Continuous mains, *i.e.*, one uninterrupted main extending over a number of (usually six) retort benches.

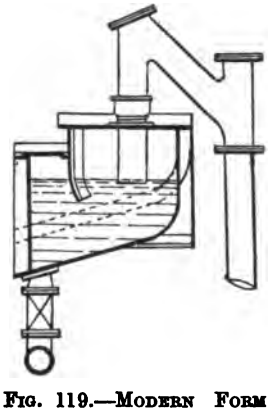


FIG. 119.—MODERN FORM OF HYDRAULIC MAIN.

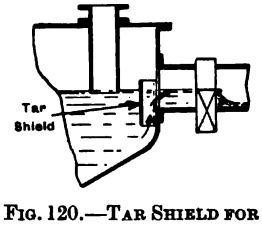


FIG. 120.—TAR SHIELD FOR HYDRAULIC MAIN.

Although the latter type is somewhat less expensive as regards first cost, the advantages lie on the side of the distinct main, which is more easily adjusted. In addition, a single setting can be readily isolated, and easier control is assured. In many of the continuous mains it is customary to avoid the use and expense of long foul mains by arranging the gas take-off (or gas and liquor take-off over a weir valve) at the extreme end of one of the sections. This method has, of course, its advantages ; but one of the chief troubles with hydraulic mains is the oscillation of the liquor therein, so that the dips are alternately lightly and heavily sealed as the crests and depressions of the waves pass around them. As the " draw " on the

hydraulic remains constant, the pressure or vacuum in the pipes connecting with the retort is accordingly affected by considerable fluctuation. When, however, the gas take-off is arranged at the end of a length of continuous main, the "draw"

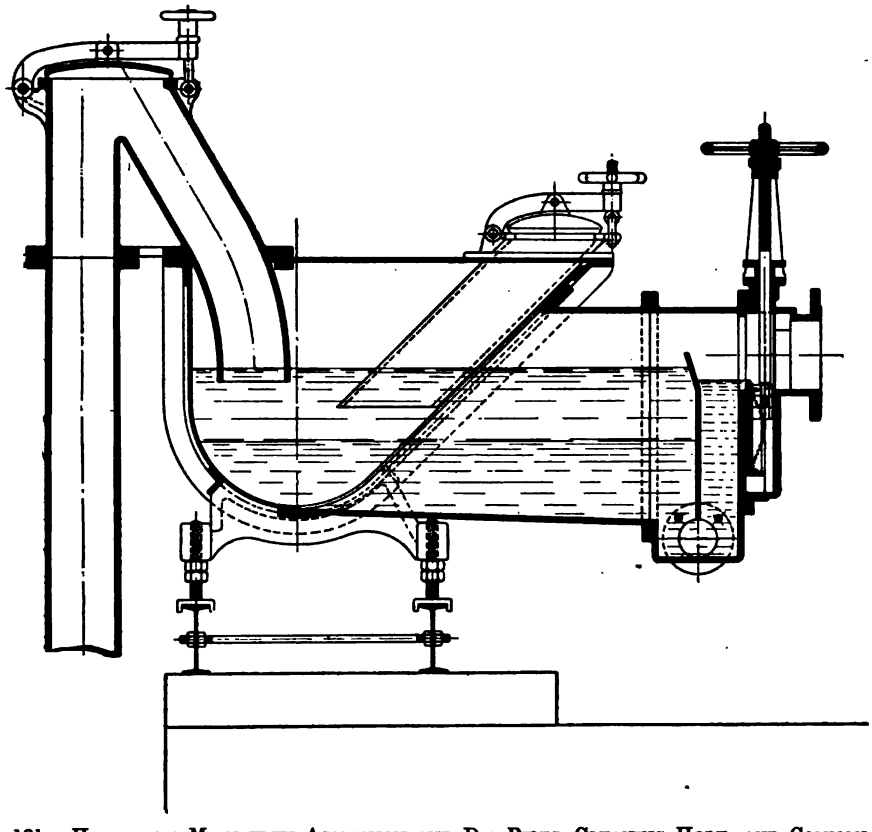


FIG. 121.—HYDRAULIC MAIN WITH ASCENSION AND DIP PIPES, CLEANING HOLE, AND COMMON GAS AND TAR DISCHARGE. DROBY SYSTEM.

from the exhauster appears to exert an influence on the surface of the long stream of liquor and to give rise to pronounced wave-motion.

Such is the effect of liquor oscillation that various means have been devised to restrict it. Among these are Meunier's floats (Fig. 123). The floats, made from wood, are placed in the hydraulic main at, or partially below, the surface of the liquor, and, by means of a series of holes

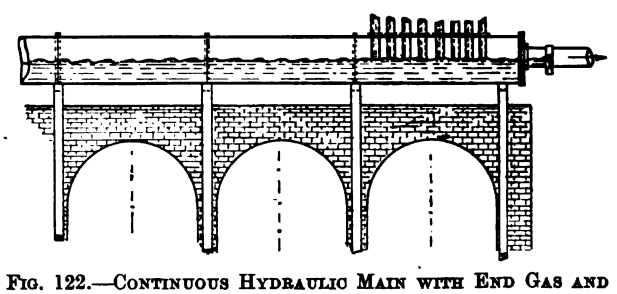


FIG. 122.—CONTINUOUS HYDRAULIC MAIN WITH END GAS AND LIQUOR TAKE-OFF, SHOWING EFFECT OF OSCILLATION DUE TO EXHAUSTER PULL.

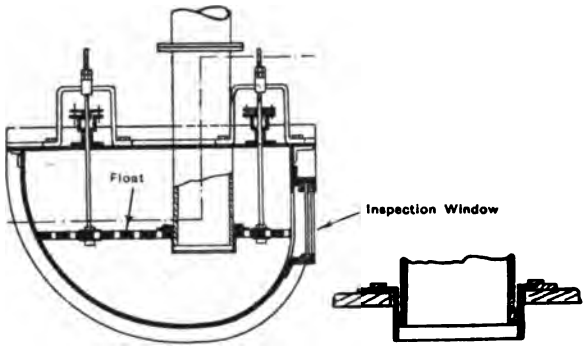


FIG. 123. FIG. 124.

MEUNIER'S FLOATS.

about 1 inch in diameter, free egress is provided for the gas. It is stated that a far more uniform level of liquid is maintained in the hydraulic, there is thorough contact between the gas and liquid, and retort pressures are more constant. Attached to the floats are dip-pipe sleeves (Fig. 124), wherewith the seal of the pipes can be either mechanically or automatically controlled by means of rods passing through stuffing boxes, as shown. The inventor states that with the application of the floats he has found an increase in gas make of from 10 to 12 per cent., whilst the trouble from naphthalene is considerably curtailed. The latter result is said to be due to the floats retaining the gas in longer contact with the hot liquid in the hydraulic main than is the case in ordinary working.

With regard to the gas take-off from the hydraulic mains, this should be arranged from the cover of the box, rather than from the side, as is so frequently found.

The method by which the hydraulic main is supported in its position above the retort bench requires careful consideration. As the chief function of the main is to provide a seal, it is essential that it should be maintained on a perfectly even keel; hence the supports must be such that they are entirely uninfluenced by any movement of the bench which may take place when heating-up occurs. In the past it was a favourite practice to bed the main on brick piers or cast-iron standards erected immediately on top of the retort bench; thus when any movement of the latter occurred the mains were thrown out of level. Modern fixings for hydraulic mains which render them entirely independent of the bench movements are shown in Figs. 118 and 121. That shown at C, Fig. 118, is, perhaps, not so desirable as the other methods, as if tightening of the main tie rods is necessary, the upper portion of the buckstays is slightly canted over, with the result that the main may develop a slight twist. All the methods are, however, subject to this effect in some degree. A very fine adjustment can be obtained by the screwed supports shown in Fig. 121.

THE FUNCTIONS OF THE HYDRAULIC MAIN

The principal functions of the hydraulic main are:—

(*a*) To act as a seal so as to prevent air being drawn up the ascension pipe when the retort doors are open.

(*b*) To act as a safety seal in the event of sudden heavy back-pressure being thrown by the apparatus following, particularly in the event of the exhauster pulling up.

(*c*) To form a receptacle for the tar and aqueous vapour condensed from the gas at the early stages of manufacture.

The seal on the dip pipes is, therefore, liable to be overcome—

(*a*) by the vacuum induced by exhausting;

(*b*) by the stoppage of the exhauster (or from some other cause) and the consequent back-pressure thrown on the hydraulic main, in which case the liquor in the main is forced up the dip pipes.

The conditions of retaining the seal are, therefore, dependent upon the relative areas of the hydraulic main and dip pipes. Theoretically, if—

x = the combined cross-sectional area of all dip pipes leading into the main
y = the total cross-sectional area of the main, and
d = the extent to which the dips are sealed when the box is open to the atmosphere,

then the total back-pressure which the pipes will withstand before letting back gas (neglecting any variation in density of the liquid)

$$= d + \left(\frac{y - x}{x} \times d\right)$$

Thus with a ½-inch seal, which is frequently found with modern methods of obtaining high gas "makes," the back-pressure which would be withstood is 6 inches, on the assumption that the respective areas x and y are as 1 to 12, or 10 inches if the ratio is 1 to 20. At the time when this function of the hydraulic main was conceived seals were commonly so much as 3 inches in depth, and capable of withstanding a back-pressure of 30 inches.

On the other hand, the amount of "draw" which can be applied to the main before the seal is broken forwards is given by the following:—

"Draw" must not exceed—

$$d + \left(\frac{x}{y - x} \times d\right)$$

providing that no overflow for the liquor is employed. That is to say, with a 1-inch seal the vacuum before the seal is overcome may equal $1\frac{1}{11}$ inch, or with a ½-inch seal 0·54 inch, again assuming a ratio of areas of 12 to 1. But on all systems of hydraulic mains some form of liquor overflow, whether it be by weir valve or tar tower, is imperative; accordingly the above formula has little bearing on the conditions of seal in the hydraulic main. If a permanent overflow is provided, then the liquor outside the dip pipe can never rise above a certain level; consequently, the difference in level of the liquid in and outside the pipe during the application of a vacuum will be brought about solely by the fall in level of the liquid inside the pipe. Hence, if a vacuum of 1-inch is applied to the hydraulic, the liquid in the dip pipe will fall 1 inch. Consequently, before the seal is broken a "draw" equivalent to the original seal can be applied.

ANTI-DIPS AND DRY MAINS

Since with modern methods of carbonization there is frequently a vacuum in the ascension pipe, so that air is drawn forward when the retort doors are open, and, furthermore, it has been shown that the safety-seal function of the hydraulic is, with light seals, practically valueless, there is strong reason to suppose that the liquor seal could be dispensed with altogether. In order, however, that the drawing-in of air, with its consequent deteriorating effect upon the quality of the gas, may be precluded, the device known as the anti-dip or dry main has been introduced. Primarily, it consists of receptacle similar to the hydraulic main, but without the permanent liquor seal, means being provided for closing the inlet to the main during the time when the retort doors are open.

The chief claims which can be made for the dry main are the following:—

(*a*) The liquor (or tar) seal is abolished, consequently any deterioration which the gas may suffer, due to the bubbling, is avoided.

(*b*) There is no continuous fluctuation of pressure or vacuum in the ascension pipe, and consequently in the retort. In fact, oscillation is absent.

(*c*) No air is pulled in during the time the retort doors are open, as is often the case with the hydraulic seal.

(*d*) Little, if any, pressure in hydraulic main and retort, therefore less scurf formed.

(*e*) If the main gets out of level the consequences are not very serious.

On the other hand, the appliance for making and breaking the seal entails the use of fairly costly apparatus, which increases the original expenditure and the wear and tear.

Anti-dips now in use may be classified under three distinct heads, namely:—

(*a*) Those where, by means of some form of plug or valve, the free-way in the ascension pipe is completely closed. This may be done by a butterfly or plug valve in the arch pipe, or by closing the open end of the dip pipe by means of a movable plug.

(*b*) Types in which the liquor is raised at will, so as to seal the dip pipes.

(*c*) Types in which the liquor is lowered at will so as to unseal the dip pipes.

The earliest forms of anti-dips were mainly constructed on the principle of the first of the above, one such being illustrated in Fig. 125. In most cases, however, these have proved more or less unsatisfactory, chiefly owing to sticking of the plugs or valves due to the accumulation of tar, or to the imperfect closing of the valves so that they are not gastight. Modern improvements of this type of anti-dips are the designs introduced by Simmonds and Davidson and shown in Figs. 126 and 127. In Davidson's system the base of the dip pipe is machined on the inside so as to form a seating for the cast-iron cone suspended from the rod passing through a stuffing box in the specially designed bridge pipe. The cone is pulled up on to its seating and released by means of a weighted lever arrangement which is operated from the charging floor. The stuffing box is packed with greasy packing. The advantages claimed for this type are that it permits of continuous draining away of

tar and liquor, so that the main is practically empty, and it does not—as is the case with so many dry mains—curtail the capacity of the main, or involve the use of complicated appliances which are out of reach during working.

In Simmonds' anti-dip the dip pipe is sealed in liquor in the usual way, and

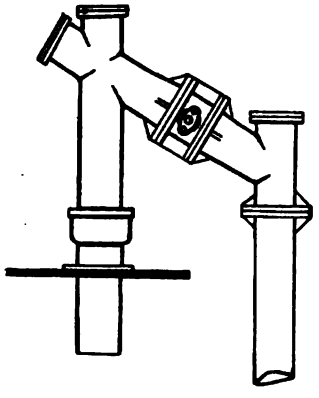


FIG. 125.—SIMPLE THROTTLE-TYPE ANTI-DIP.

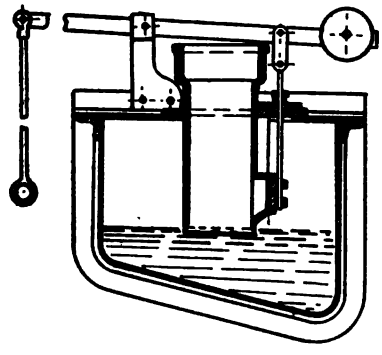


FIG. 126.—SIMMONDS' ANTI-DIP.

an aperture for the passage of the gas is provided in the side of the pipe above the liquor level. At this point a square valve face is cast on to the side of the pipe, the area of the gas outlet being equivalent to the cross-sectional area at the base of the pipe. The faced slide valve is operated by means of a rod passing through a stuffing-box and connected to a counter-weighted lever. The operating handle extends to the charging floor, being held down during the period of gas making so that the seal is by-passed, and released whilst the retort doors are open in order to prevent the intake of air. A flange is provided at the valve-rod gland which gives sufficient room for the valve to be withdrawn when re-facing is necessary.

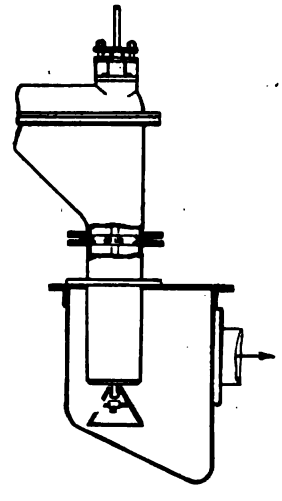


FIG. 127.—DAVIDSON'S ANTI-DIP.

The same principle of interposing a liquor seal is made use of in Cort's anti-dip (Fig. 128), but in this case a double dip pipe is employed, the outer pipe being in the nature of a sliding sleeve. When the retort doors are closed the sleeve is drawn upwards to its fullest extent, so that the gas passes direct from the inner pipe to the foul main. When the doors are opened the sleeve, by means of suitable gear, is dropped, and forms a liquor seal which precludes the possibility of air going forward.

Helps' anti-dip (Fig. 129) is unique in that no mechanically operated appliance is entailed; hence one of the chief difficulties with dry mains is avoided. Attached to the back of the hydraulic main, and running

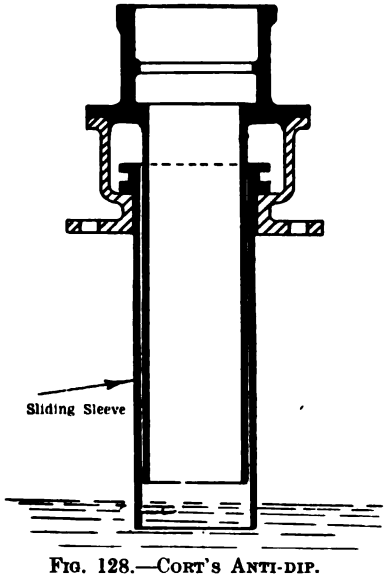


FIG. 128.—CORT'S ANTI-DIP.

to the displacement chamber. chamber, with a corresponding rise in level in the hydraulic, the latter rise being sufficient to seal the dip pipes, thereby closing the free-way of the ascension pipes. The difference in level will, of course, be the same as the difference in pressure of the pressure gas used and the vacuum produced by the exhauster. In this system it will be noticed that all retorts in the bench are simultaneously sealed, whether their doors are open or not. A wheel is attached to the three-way valve, and the change is effected by a chain passing round the former and hanging down to the stage floor. It will be seen that the only working part, the three-way valve, never comes in contact with the newly made gas and tarry vapours.

the whole length of the main, is a displacement chamber. Communication is effected between the hydraulic and displacement chamber by means of the small pipes, as shown, whilst a three-way valve has two of its ports connected to the two connecting pipes respectively, and the third to a supply of gas under pressure, taken back (say) from the mains leaving the purifiers. The displacement chamber, by a turn of the three-way valve, is accordingly put in connexion with the vacuum exerted on the hydraulic by the exhauster or with the pressure in the mains beyond the purifiers. The level of liquor in the hydraulic is set so as to give a clear passage through the dip pipe; and, when the retort doors are shut, the displacement chamber is under a similar vacuum to that prevailing in the hydraulic. When the retort doors are opened, however, the pressure gas is admitted This causes a depression of the liquid in the

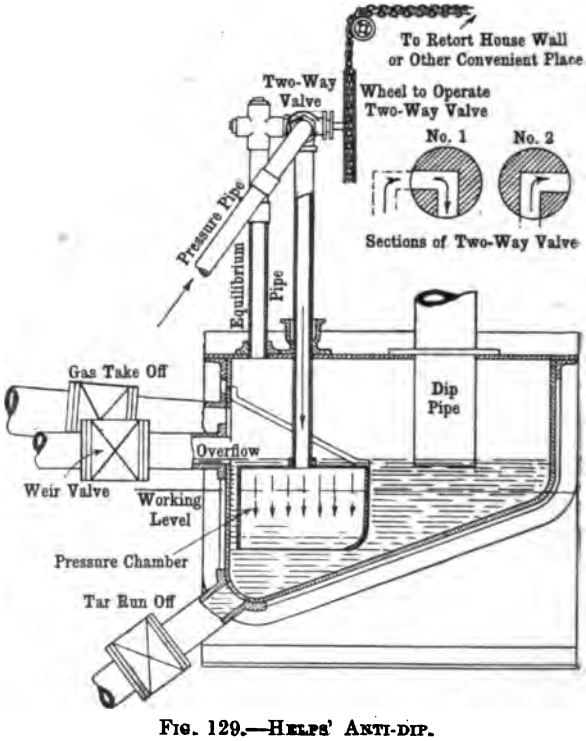


FIG. 129.—HELPS' ANTI-DIP.

TAKE-OFFS FOR TAR AND LIQUOR

For many years, until recently, the weir valve was by far the most common method in use for disposing of the liquor and tar from the hydraulic main. As before explained, the gas, liquor, and tar were removed through a common outlet, a tar shield usually being provided, so that liquor formed the greater part of the liquid remaining in the hydraulic. The three products of distillation then flowed together to the foul main, from the bottom of which the liquids were drawn off through seals and run to the storage wells, where separation, due to gravity, took place. In spite of the introduction of more effective appliances, the weir valve is still in fairly common use, and forms a ready and reliable means for the regulation of seals. The construction of the valve is simple, and is shown in detail in Fig. 130.

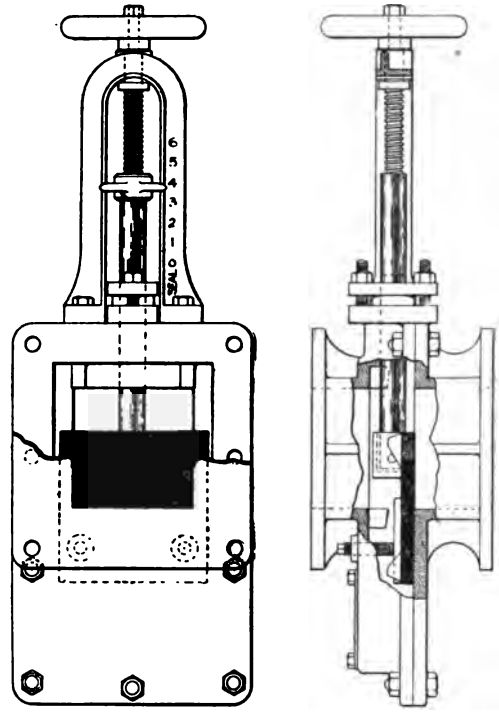


FIG. 130.—TYPICAL WEIR VALVE.

A more recent means for the disposal of tar and liquor is that introducing the principle of the tar box, in which the gas outlet is distinct from that of the liquids, and seal regulation is effected by the height of overflow of the latter. The principle introduced is in reality that of the U-gauge, one limb being the hydraulic main and the other limb the tar-overflow pipe. The arrangement will be readily understood by reference to Fig. 131. It will be seen that the tar-box casting is attached to the side of the hydraulic, seal regulation being effected by the running socket, as shown. Owing to the greater density of the tar, the height of the liquid level in the tar box will be slightly below that of the liquor in the hydraulic main. An important feature is the equilibrium pipe between the tar box and main, which ensures the same conditions prevailing above the two columns of liquid. Tar boxes of this type are, at the present day, very seldom erected, as they are not always reliable in their action and entail a good deal of attention. They are,

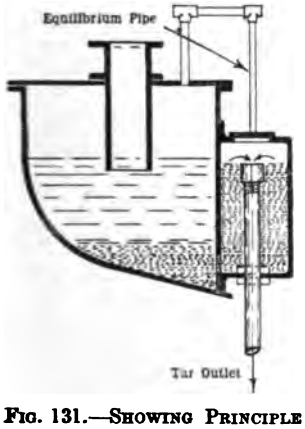


FIG. 131.—SHOWING PRINCIPLE OF ACTION OF TAR BOX.

moreover, expensive in the first instance; and have almost wholly given way to the principle of the Dillamore tar tower, which provides an extremely simple and effective means for both the regulation of seals and the collection of tar and liquor.

TAR TOWERS

Probably one of the most striking features of present-day retort-bench equipment is the manner in which the Dillamore tar tower—an appliance originally introduced many years ago, but with mixed results—has forced its once-despised merits upon the attention of the gas engineer, so that it is now looked upon as furnishing the most ideal means for seal regulation and tar and liquor disposal. It may be said that each engineer who favours tar towers has his own particular way of fitting them up; hence no hard-and-fast rules can be laid down. In general, however, it will be found profitable to aim at leaving the interior of the tower as unencumbered with pipework as possible, and with this end in view the author suggests the scheme shown in Fig. 132 as being the least costly and the most satisfactory from the standpoint of reliability. The merits of tower systems are too well known to need repetition here. The more common defects which may go unnoticed for a time may be briefly summarized as follows:—

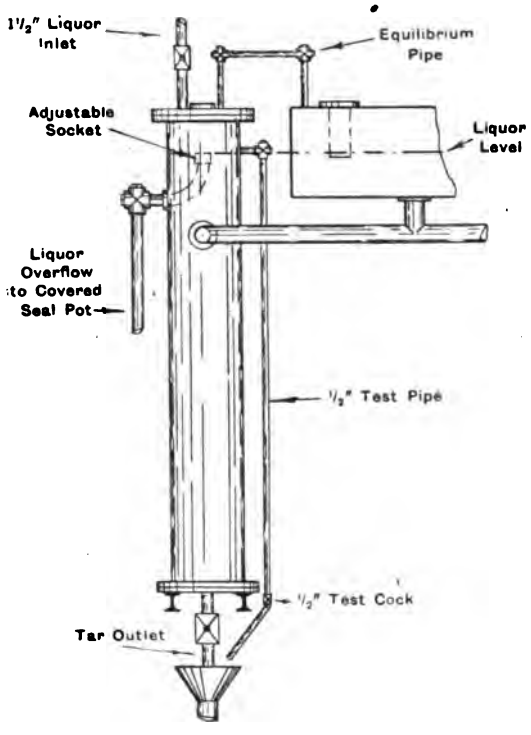


FIG. 132.—AN EFFECTIVE TAR TOWER SCHEME.

(*a*) In many cases an external or internal seal is employed, so that the liquor flow from the box may be readily seen. The warm liquor flowing out in this way is responsible for appreciable ammonia losses, and the liquor should preferably be led to a closely covered seal-pot.

(*b*) Choked or partly choked equilibrium pipes may go unnoticed for some time, with the result that the seal on the dip pipes is not what it is thought to be.

(*c*) It must be remembered that a tar tower and the hydraulic main, connected together by the tar inflow pipe, in reality form a U-gauge, and the weights per unit of area of the two columns balance one another. Consequently, fluctuations in specific gravity in the liquid in the two columns will be responsible for a rise or fall in level, hence alteration of the seal. Differences in temperature are also followed

by similar effects. It has been shown that if a variation of 30° C. occurs in the temperatures of the liquid in the tower and hydraulic main (for instance, if the temperature of the liquor in the tower rose from 20° C. to 30° C. and that of the liquor in the hydraulic main fell from 70° C. to 60° C.) this alone may be responsible for a variation of 4½-tenths in the seal. To minimize this effect as far as possible it is advisable to connect the main tar pipe to the tower as high up as can reasonably be done, and to ensure that the tower is flushed down before the accumulated tar reaches the level of this pipe.

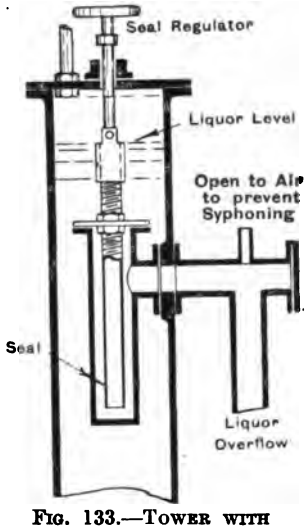


FIG. 133.—TOWER WITH INTERNAL SEAL.

(*d*) A special means should be provided for guarding against the possibility of unsealing the dip pipes when the tower is discharged. It is usual to run liquor into the tower whilst the tar is being run off; but even under such conditions the outward flow may be greater than the inward flow, thus the level will fall. A simple means of seeing at a glance whether or not the seal is being maintained is to fit a ½-inch test pipe, as shown in Fig. 132. When the tower is flushed the ½-inch test cock is opened, and so long as liquor passes down this pipe a seal is ensured.

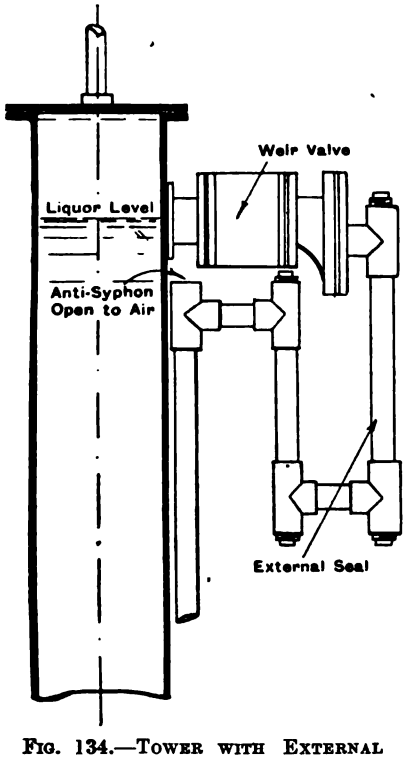


FIG. 134.—TOWER WITH EXTERNAL SEAL.

(*e*) The only questionable drawback to the liquor take-off from the tower as shown in Fig. 132 is the possibility that the outlet pipe may become choked, and, owing to the liquor flowing into a covered seal pot the stoppage may not be immediately noticed. In this case the tower gradually fills, with the result that a heavy seal is thrown upon all the dip pipes. It is scarcely necessary to mention that on all installations of the kind, bends in the pipe work should be rigidly avoided, and plugged crosses should be used wherever possible.

(*f*) It is always advisable to provide for a constant trickle of liquor when towers are in use. Although this is frequently admitted at the hydraulic main, it is far preferable to arrange for the supply direct to the tower—the latter being cooler, there is less likelihood of ammonia loss.

(*g*) In cases where outside or inside sealing arrangements are provided, care must be

taken to ensure that all possibility of syphoning is avoided. To this end, some portion of the pipework must be open to the atmosphere, whilst it will be noticed that in the system shown in Fig. 132 this is not necessary, as syphoning could not take place.

Sketches of the outside and inside seal types are given in Figs. 133 and 134, and the anti-syphon precautions will be noted. A decidedly uncommon and novel arrangement is that shown in Fig. 135. In this instance the depth of seal on the dip pipes is entirely governed by the constant overflow of tar, the outlet pipe for the latter being brought up from the base of the tower to a point on about a level with the bottom of the hydraulic mains. Accordingly, it is tar, and not liquor, which is constantly trickling away; and since more liquor than tar is formed, a special draw-off cock for the former is provided about two-thirds of the way up the tower, and a certain amount of liquor is daily run off so as to ensure there always being tar at the bottom of the tower. The chief advantage claimed is that the liquor may be worked up to greater strength than is the case with the more ordinary tower systems, whilst there is no constant stream of warm liquor running away to the wells.

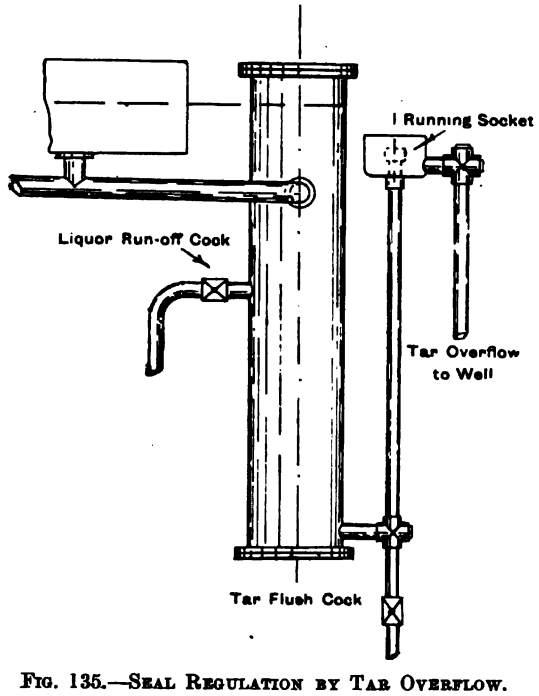


FIG. 135.—SEAL REGULATION BY TAR OVERFLOW.

An uncommon idea, infrequently met with, is that shown in Figs. 136 and 137. It consists of combining the usually distinct apparatus of tar-tower and retort-house governor. The tower is made considerably higher than is general, and the upper portion contains a special receptacle which takes a floating bell of greater diameter than the tower proper. The bell chamber is closed by a cover plate having a centrally disposed hole through which a rod passes, by means of which the governor may be adjusted. Immediately below the bell chamber is the gas inlet. The subsequent passage of the gas may be seen from the section given in Fig. 137. The governor valve serves to throttle the passage of the gas should the vacuum increase above the normal, while, should the vacuum decrease, the valve is raised, with a consequent increase in the area of the gas passage, due to the increase in pressure of the gas on the bell.

During the last few years there has been a growing tendency to erect tar towers built up from mild steel plates and sections. It is somewhat difficult to understand

why this should be done, for the ordinary cast-iron pipe cannot be excelled, and is extremely cheap. Possibly, the steel tower was originally introduced owing to the objection to sending cast-iron work long distances, when it is liable to rough handling and damage.

The experience of Mr. J. G. Newbigging in connexion with ammonia losses may be mentioned, as bearing out the arguments that the internal or external seals with tar towers are unnecessary and actually wasteful, and that it is far preferable to take the liquor direct to an effectively sealed pot. It had been Mr. Newbigging's general custom to run liquor into his mains from an overhead tank, when striking differences in the amount of free and fixed ammonia led him to make investigations. Two deductions were made, the first being that ammoniacal liquor constantly overflowing the weir valves was in such a state that free ammonia was being driven off in large quantities, and, consequently, any exposure to either an air current in the pipe line or to the atmosphere meant a probable source of serious loss. To overcome such drawbacks, water, instead of liquor, was used for flushing the hydraulic mains, and in this manner ammonia loss was curtailed, owing, it is said, to a lower percentage of free ammonia in the liquor overflowing the weir valves. In view of these results, it might appear advisable to admit water instead of the usual trickle of liquor to the hydraulic mains, but the author considers the practice undesirable.

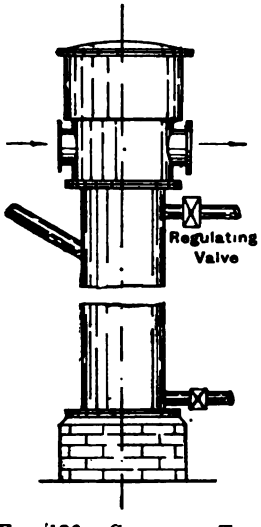


FIG. 136.—COMBINED TAR TOWER AND RETORT HOUSE GOVERNOR.

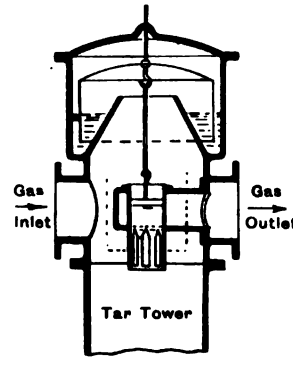


FIG. 137.—SECTION OF COMBINED TOWER, SHOWING THE GOVERNOR.

THE PITCHING-UP OF MAINS, ETC.

The pipes which are used for conveying the tar and liquor from the hydraulic mains to the storage well are often a source of trouble owing to the adherence of pitchy matter to the inside, thereby causing blockage. This is particularly the case where the pipes are subjected to radiated heat from the retort bench. The most effective means of collecting liquor, and at the same time furnishing a flushing system for the draw-off pipes and hydraulic, is to provide a tank into which all liquor running from the foul main, hydraulic mains, or tar towers, is taken. This liquor is then raised by means of a pump to an upper tank a few feet above the retort bench, and provides the constant feed to the tar towers as already explained. The chief function of the pump, however, is that of periodically flushing out the tar pipes. This is effected by fitting a connexion from the delivery of the pump to the run-off pipes of each

individual tar-tower system. Accordingly a flush of liquor at considerable pressure can be pumped backwards through the pipes and into the hydraulics. A short period of such flushing carried out once a day, or even once during each shift, precludes the possibility of stoppage. The system of liquor tanks, moreover, has other advantages, in that the warm liquor coming straight from the towers and foul main is permitted time to cool down before being discharged into the storage well, thus curtailing loss of ammonia. A further advantage is that the liquor run into the towers or mains can be kept in continuous circulation (only the surplus being allowed to drain off to the well through an overflow in the lower tank), which results in a greatly increased strength being obtained. When liquor is circulated in this manner

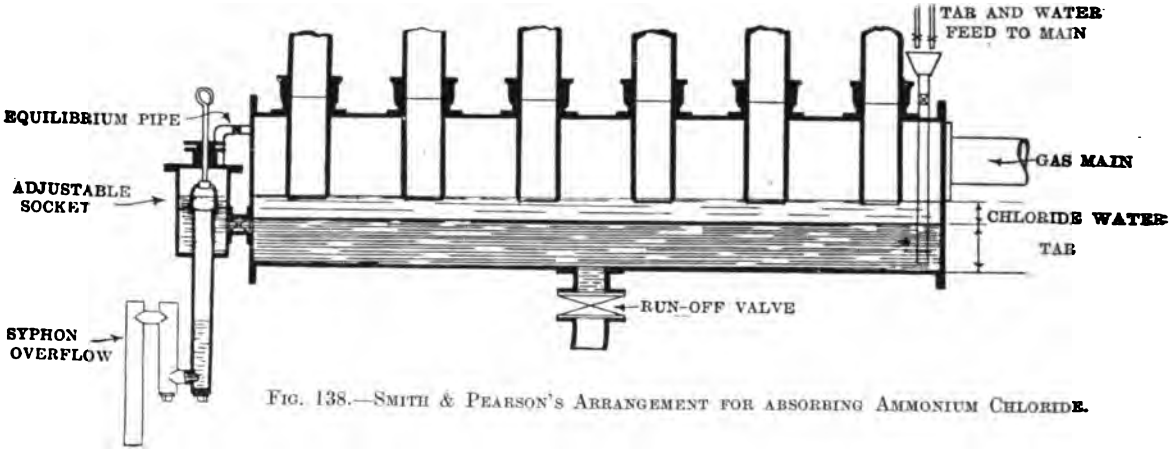


FIG. 138.—SMITH & PEARSON'S ARRANGEMENT FOR ABSORBING AMMONIUM CHLORIDE.

it will usually be found that the proportion of "fixed" ammonia is appreciably greater than when ordinary methods are employed.

Smith and Pearson, in the course of their researches carried out with the Birmingham coal-testing plant, found that, so far as the pitchy deposits in the hydraulic main were concerned, the chief binding material in the pitch appeared to be ammonium chloride taken up from the gas in the hydraulic main. In order to eliminate this effect, they absorbed the chloride before it could reach the tar by interposing a layer of water, 3 inches deep, on top of the tar. The water was run in hot, so that little free ammonia was taken up, and the chloride in the gas was reduced. Considerable benefit resulted from the arrangement, which is diagrammatically illustrated in Fig. 138.

HYDRAULIC MAIN AGITATORS

Where modern methods for the drawing-off of tar and the flushing of hydraulic mains are in use, little trouble is experienced from stoppage and erratic working due to "pitching-up." The disorganization resulting from the latter, however, has in some cases been sufficiently severe to warrant the use of special agitating devices.

A common type of apparatus for the purpose is illustrated in Fig. 139. It con-

sists of an endless chain passing over two sprocket wheels, situated one towards each end of the hydraulic main. Projecting arms or scrapers are attached to the chain, which is so arranged that the underside drags along the floor of the main. By means of a projecting spindle the chain can be set in motion at periodical intervals. Needless to say, it is strongly inadvisable to encumber the hydraulic with apparatus of this type when it can possibly be avoided. If flushing or agitation is desired, it should be carried out by liquid and not mechanical means.

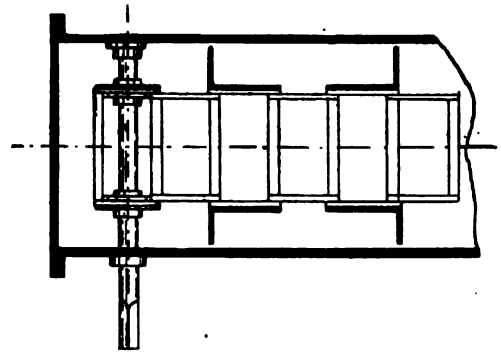


FIG. 139.—HYDRAULIC MAIN AGITATOR.

Modern hydraulic mains all tend to be somewhat smaller and more shallow than many of the old cast-iron types. The tendency is certainly to be encouraged, for the function of the hydraulic is not that of a storage tank, and the depth of liquor should be as shallow as possible, providing that it satisfactorily performs its primary duty of ensuring a seal. If a considerable volume of liquid is always allowed to remain in the hydraulic, there is a tendency for distillation to take place; and, as tar will inevitably settle out, the formation of pitch is only a matter of time, unless special precautions are taken to keep it down.

THE FOUL MAIN

The foul main may be called upon to perform more duties than one, and amongst other functions it provides:—

(*a*) A gas conduit between carbonization and primary purification plant.

(*b*) A drain pipe for liquor and tar.

(*c*) A primary condenser.

So far as the last duty is concerned, the total length of foul main should be included when calculations for condensing capacity are made.

The size of the foul main must depend upon the combined areas of all pipes leading into it. Theoretically, the cross-sectional area should be equivalent to the sum of the areas of the latter pipes, but this is never carried out in practice, first because mains of such capacity are unnecessary owing to the condensation rapidly taking place, and because the foul main is delivering gas more or less continuously, whereas there is a sudden rush of gas into each hydraulic main as charging takes place.

Generally speaking, the following sizes for foul mains are those prevailing, and may be safely applied:—

Capacity of Bench per 24 hours.	Size of Foul Main. If one.	If two.
(*a*) 30,000 to 100,000 cubic feet	6 inches to 9 inches.	—
(*b*) 200,000 to 500,000 cubic feet	12 inches to 15 inches.	—
(*c*) 1 million to 1¾ million cubic feet	18 inches.	14 inches.
(*d*) 2 million to 3 million cubic feet	24 inches.	18 inches.

Another rule is to make the foul main (if it delivers all the gas) of 125 per cent. the area of the main connexions in the works.

Retort benches in the past were invariably supplied with a cast-iron foul main, but the modern practice is to construct the latter from lap-welded steel plates or solid drawn tubes. When the foul main is of greater diameter than 12 inches, steel should, as a general rule, be used, and in such cases it will usually be slightly cheaper than cast-iron. A further recommendation is that owing to the thinner metal walls employed in the steel pipe the outward radiation of heat is greater, hence the cooling effect on the gas is very much more pronounced.

As the foul main is situated above the retort bench it is liable to undergo considerable expansion when the heats are raised ready for work; accordingly some means must be introduced for the prevention of breakage. With the cast-iron main, the lead joints at the spigots will be sufficient to cope with any change of length, and flange joints should, therefore, be avoided, unless some form of expansion joint is inserted.

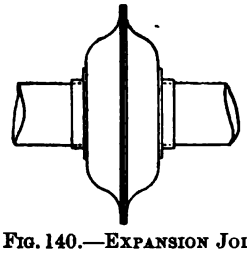


FIG. 140.—EXPANSION JOINT FOR FOUL MAIN.

The steel foul main, having no flexible joints to yield to movement, should—if of any length—always be provided with an expansion joint similar to that shown in Fig. 140. In the usual way one of these joints will be necessary for each 100 feet of pipe. In modern work the foul main is usually supported on the cross-stays, or from them by chains or steel straps.

RETORT-HOUSE GOVERNORS

The retort-house governor is an auxiliary, more or less essential in the larger works, of comparatively recent introduction. It differs from the ordinary station type of governor (which forms the last piece of apparatus through which the gas passes before leaving the works) in that whilst the latter is employed with the object of reducing pressure, the retort-house governor is interposed for the purpose of reducing the intensity of vacuum created by the exhauster. This, however, is not its primary function. In the same way that the station governor ensures a steadiness of pressure in the consumers' services, whatever may be the demand, so should the retort-house governor ensure a constant vacuum in the hydraulic main, whatever the volume of gas coming away from the coal charges. The intensity of vacuum desired is obtained by means of "loading" on similar lines to the method prevailing with station governors.

Before the introduction of this apparatus the required vacuum on the foul main was obtained by regulation of the speed of the exhauster; whereas the uniformity of the "draw" was controlled as effectively as possible, but not without considerable difficulty, by means of the ordinary type of exhauster-governor working on the throttle of the engine or a by-pass. (For description, *see* Chap. XIII.) This method of regulation is still in vogue in those works where no retort-house governor is installed.

The application of the retort-house governor requires some consideration in relation to the working of horizontal settings, owing to the operation of gas making

being necessarily intermittent, and to the impracticability of charging the whole bench of retorts at the same moment. For instance, if a single retort bench, working into a common hydraulic main, is considered, it will be seen that, owing to the different periods at which the distinct rows of retorts have been charged, there will be a large volume of gas coming away from some dip pipes, whereas those retorts in which the charges are nearly spent will be yielding little or no gas. But the object of the retort-house governor being to maintain a constant "pull" whatever the quantity of gas coming away (and providing all dip pipes are equally sealed), there will be a similar vacuum on each retort; that is to say, there is every likelihood of drawing furnace gases up the pipes from those retorts where the charge is spent. Under the circumstances, the ideal would be to charge up an entire set, or series of settings, at one time (instead of carrying out the ordinary practice of travelling through the whole length of the bench on a definite row of retorts), and to interpose a retort-house governor for each unit so worked. The vacuum could then be gradually reduced as the period of carbonization on each distinct section advanced. Such procedure, however, is scarcely possible in practice; and would, moreover, be somewhat antagonistic to the purpose in view of those engineers with a penchant for high makes per ton.

Owing to the fact that the retort-house governor works in connexion with a system of mains under a vacuum, the holder bell—or other reservoir—in communication with the main receives no support from the gas, consequently buoyancy has to be imparted to it by other means. In general, these governors may be divided into two groups, namely—

(*a*) those deriving their buoyancy from a system of air floats within the holder bell, and being regulated by direct loading of the latter;
(*b*) those in which no air floats are employed, but which are rendered buoyant by a counterbalance.

Both types are in common use, but (*b*) is probably preferable, owing to the tendency of the float casings to corrode. The arrangement of the air chambers is shown in Fig. 141, and it may be pointed out that for retort-house governors this is preferable to fixing the floats with an exterior annular space as in Fig. 142. With the latter arrangement the governor frequently operates in too "lively" a manner for the best results. On the other hand, for exhauster governors, the annular chamber is preferable.

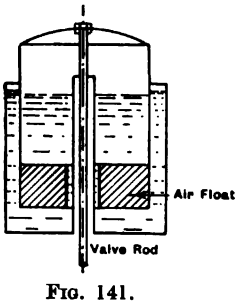


FIG. 141.

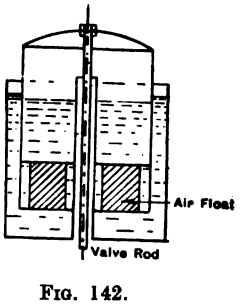


FIG. 142.

The best place for the governor is on top of the retort bench, and as close up to the end of each section of the foul main as possible. It is not so sensitive when fixed

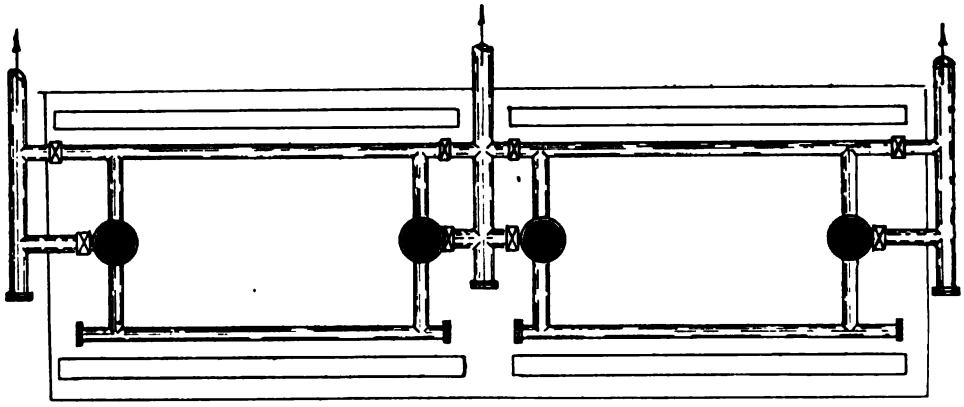


FIG. 143.—ARRANGEMENT OF FOUL MAINS AND RETORT-HOUSE GOVERNORS FOR LARGE BENCH.
NOTE.—VALVES (NOT SHOWN) ARE REQUIRED AT THE BASE OF EACH GOVERNOR.

on the inlet or outlet of the condensers, as sometimes found. In a retort house of any size, more than one governor is necessary, and the different sections of foul main will best be controlled by some arrangement as that shown in Fig. 143. By-passes are advisable whenever they can be arranged for, as the governors will usually require attention about every four months, when both tank and valve should be cleaned.

A typical governor of the counterbalanced bell type, designed on Parkinson and Cowan's system, is illustrated in Fig. 144. The passage of the gas along the foul main is governed by the sliding reel which depends from the centre of the governor bell. At the same time communication between the holder and the main on the retort-bench side is effected by the service pipe shown. By means of the weights the bell is so poised that the desired vacuum is obtained. Should the gas coming from the retort bench increase in volume, then the vacuum in the foul main will decrease, with the result that there is less "sucking-down" on the bell, which accordingly rises. This movement raises the reel and opens the gas-way until the previous conditions of vacuum are regained, and *vice versa*. This type of regulation, with the open reel, is to be preferred to those governors in which the gas in its tarry condition is forced to travel through narrow slots. These slots lend themselves to blockage, particularly when a system of dry mains

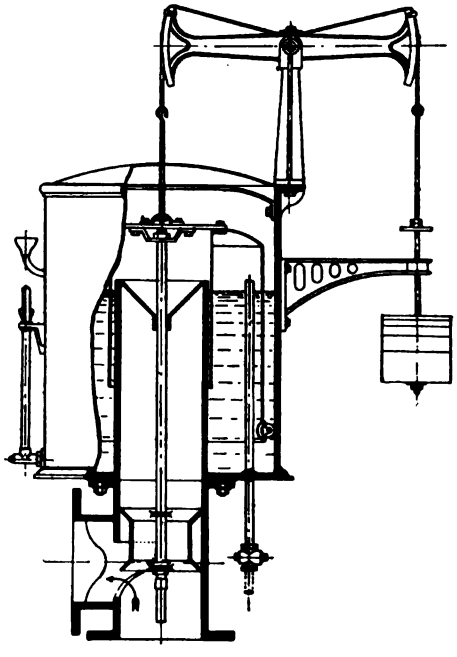


FIG. 144.—RETORT-HOUSE GOVERNOR.

is in use. It is as well to arrange for a thin layer of oil on the surface of the holder water.

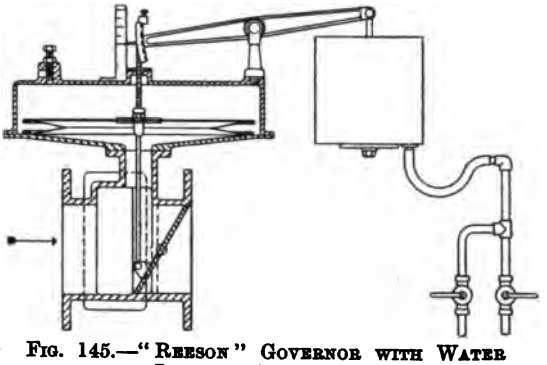


FIG. 145.—"REESON" GOVERNOR WITH WATER LOADING ATTACHMENT.

A new departure from the ordinary apparatus is the "Reeson" governor, shown in Fig. 145. In this apparatus the gasholder principle is done away with, and its place is taken by a small flexible reservoir formed by a leather diaphragm. This diaphragm, being in direct communication with the foul main, is caused to collapse or distend in accordance with the volume of gas passing along the main. The movement of the diaphragm then operates the butterfly valve and increases or diminishes the free gas-way. In this case a water-loading attachment for regulating the intensity of the vacuum is shown. The chief merits of the governor are its compactness and the small possibility offered for deterioration by corrosion.

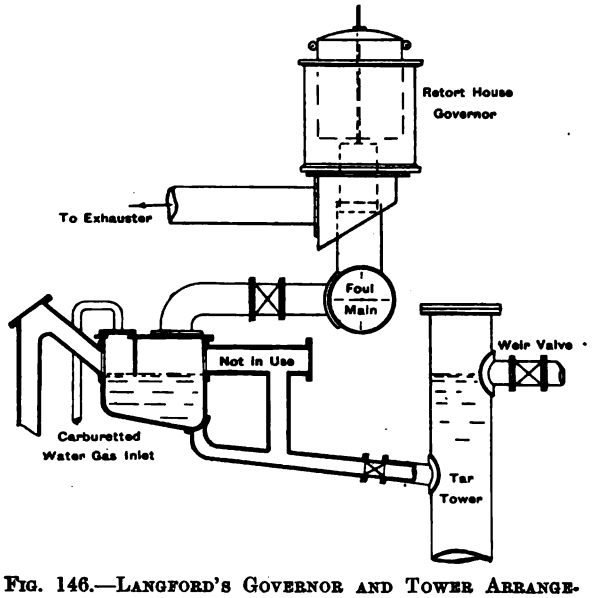


FIG. 146.—LANGFORD'S GOVERNOR AND TOWER ARRANGEMENT.

For the purpose of regulation, many medium-sized works employ an ordinary butterfly valve operated from a bell.

A novel hydraulic main and gas take-off arrangement has been introduced by Langford. This is shown in Fig. 146. It will be seen that the gas is taken off from the top of the hydraulic, whilst the liquor overflows by the weir valve attached to the tower and maintains the seal. Originally, both gas and liquor were removed in the ordinary way via the weir valve on the hydraulic, but excessive oscillation of the liquor occurred, which was particularly objectionable, owing to the peculiar type of ascension and dip pipes, unsealing frequently occurring. With the gas outlet moved to the top of the hydraulic, the vacuum from the exhauster was exerted at right angles to the surface of the liquid, thus oscillation was considerably curtailed. The disposition of the retort-house governor will also be noticed, whilst a further uncommon practice is that of leading the carburetted water gas direct to the hydraulic main, where it is intermixed with the coal gas.

CHAPTER VIII

THE MECHANICAL HANDLING OF MATERIALS

THE application of machinery to the handling of all types of gasworks material has during recent years undergone considerable extension, so that, nowadays, even establishments of a comparatively small order can instal certain types of labour-saving plant to advantage. Moreover, recent incidents in the labour world and the perfecting of the more or less crude apparatus of former years has added a certain stimulus to the introduction of mechanical means for performing a host of duties originally carried out by hand. The result is that whereas in 1893–7 about twenty men were required to produce a million cubic feet of gas per diem, to-day, in large installations of vertical retorts, the number is only four. Roughly speaking, it may be taken that the saving of a single man's wages warrants a capital outlay of between £500 and £600 on machinery. When deciding upon the question of the introduction of mechanical plant, however, considerable thought is necessary, so that the various charges and contra charges are correctly balanced the one against the other.

The principal considerations which each engineer must apply to the case in question may be briefly enumerated as follows:—

(1) Can the working costs be curtailed, and if so, what will be the annual saving?

(2) Will better carbonizing results follow the introduction of machinery, and will more gas be obtained from the plant used and land occupied. If so, what will be the effect on the wear and tear of plant?

(3) Is the saving represented by (1) and (2) likely to be sufficient to meet the standing charges for interest on capital expenditure, depreciation and repairs?

(4) Will efficiency be sacrificed in order to effect the apparent economy? Loss of efficiency may mean losses in other directions.

(5) Will the reduction of labour relieve the management of any difficulties not actually measurable in terms of £ *s.* *d.*?

When the works is of any magnitude it will be found that all these conditions can be replied to in the affirmative, particularly when it is a matter of conveying material from one point to another, or from a low level to a higher level.

As a matter of fact, retort-house machinery is not profitably employed in small works, although those manufacturing 20 million cubic feet or over per annum can to advantage instal such types as the "Rapid" or "Manual" machines, which require no mechanical power, and which may be classed as labour-saving devices though not necessarily causing much diminution in expenses.

As an example of the economy in labour to be effected on larger works, the case of the 500 million works considered in Chapter I may be taken. The coal gas made per diem in this instance amounts to 1,800,000 cubic feet, and the total outlay involved in elevators, conveyors, coal breakers, charging machinery, and coke-handling plant is given as £7,250. Allowing the normal figures of 5 per cent. for interest on capital, 3 to 4 per cent. for maintenance, and 7½ per cent. for depreciation (*i.e.* a total of 16 per cent.), the annual saving which must be effected is £1,160. This means a reduction in numbers of about 13 or 14 men, or (say) 4 or 5 men from each shift per day. About 35,000 tons of coal per annum would be handled, which means that a saving of 8*d.* per ton is necessary to meet the above expenditure. Accordingly, those in authority would have to be positively assured that such a saving would follow the introduction of machinery. On the works in question there is little doubt that this economy—amounting to about 0·7*d.* per 1,000 cubic feet of gas produced—could be effected.

Labour-saving machinery may be applied on gasworks for the following purposes :—

(*a*) The charging and discharging of retorts.

(*b*) The conveyance of coal from point of delivery to point of consumption.

(*c*) The breaking up of coal to the required size.

(*d*) The conveyance of coke from the retorts to a suitable storage place, or to other machinery for grading, screening, or washing.

(*e*) Labour-saving appliances in the retort house, such as mechanical pokers and clinkerers.

The mechanical handling machinery introduced in gasworks is almost solely used in connexion with the retort house, although on larger works other raw materials or by-products, such as oxide of iron or sulphate of ammonia, may be profitably dealt with in this manner. In fact, in any instance where a saving can be shown, after consideration on lines such as those already indicated, the instalment of machinery is justified.

CHARGING AND DISCHARGING MACHINERY FOR RETORTS

The past decade has witnessed a striking change in the design of machinery used for the filling and emptying of horizontal retorts. The introduction of the heavy charge and the mass system of carbonization has been responsible for much of this modification, so that discharging apparatus embodying the principle of the rake—at one time a very common type—has almost entirely disappeared. This is due to the necessity for leaving a considerable space above the charge in the retort in which the rake head may travel.

Stoking machinery employed in operating the retorts may be primarily classified under the following headings :—

1. Machines designed to minimize the labour of charging or discharging but which require no power other than manual labour for their operation.

2. Machines charging simultaneously from both sides of the bench, such as the

Arrol-Foulis, or West's scoop charger. These types of machines, though still at use in many instances, are scarcely consistent with modern requirements.

3. Machines discharging from both sides of the bench simultaneously. These include those types worked on the rake principle, and which are not suitable for heavy charges.

4. Machines charging from one side of the bench only.

(*a*) Projectors.

(*b*) Those embodying the principle of the conveyor chain.

5. Machines discharging from one side only. These are exclusively worked on the principle of the pusher.

6. Discharging chargers, which simultaneously empty and refill the retort.

The last-named type, though not altogether satisfactory at the time of its introduction, is now reaching a stage of perfection which has resulted in its more general adoption. One of the chief disadvantages attending the use of the earlier types was the impossibility of working heavy charges, owing to the necessity for leaving the upper portion of the retort clear for the return of the conveyor chain. This difficulty has now, however, been surmounted.

It would not be possible to describe fully here the details of construction of all the machines now in operation in gasworks for filling and discharging retorts. It is merely proposed to consider the most familiar examples, and to indicate briefly the principles upon which they operate.

The engineer who is contemplating the introduction of machinery should decide on the type of plant, in conjunction with the apparatus for conveying coal, before proceeding with the design of the buildings and retort plant. Many makers have different types of machinery, such as those with or without storage hoppers, measuring chambers, etc. It will, therefore, be found advantageous to settle upon the type and make at the outset. Once the machine is decided upon there are many points requiring attention, and at this juncture discussion between buyer and maker will prove of great assistance in the design of new buildings or alteration to existing ones. The maker should furnish a plan showing the over all dimensions of his machine, the clearances required at the front, back, and sides, also the total weight when loaded with coal, and the static load on each wheel. In addition, he should state the probable maximum load on any wheel due to abnormal circumstances—such as unevenness of the running track or excessive thrust caused by stoppage in the retorts, etc. (*see* page 45). If the rail gauge is known the floor can then be designed. The majority of makers have a regular form upon which the necessary requirements for their machines are set out, but they can, of course, deviate from some of them (within reasonable limits) without affecting the efficiency of the machine. In obtaining tenders the engineer should give the salient requirements from the machine, such as the number of retorts to be charged, their size and arrangement, and the method of coal-feeding proposed.

So far as working capacity is concerned separate charging and discharging machines are, naturally, capable of dealing with a greater number of retorts than are the combined types. Machines operating from one side of the bench only are

fast replacing those which operate simultaneously from both sides. In the latter type the number of operators is doubled, and the capital cost is increased by about 50 per cent. Where a chain or other working part enters the retort, the retort must be kept a better shape, and usually requires scurfing more frequently.

The working portions of the machine liable to breakage should be readily interchangeable, and the engineer should know what spare parts he is expected to stock, as such items have an important bearing upon the efficiency and cost of upkeep of the machine. It may be noted here that the average life of a De Brouwer belt is from 12,000 to 20,000 tons of coal. The belt costs about £15 to replace, and represents an expense of about 0·225*d.* per ton of coal handled.

The Arrol-Foulis Hydraulic Charger

This charging machine is usually operated in conjunction with a hydraulic discharger. Chargers are provided on each side of the retort bench and deliver the coal from both ends up to the centre of the retort. Generally speaking, a system of overhead storage hoppers is provided in the retort house, and by means of suitable shoots the coal is led into the hopper carried on the front of the charger. The hopper on the machine is capable of holding sufficient coal to charge about twenty retorts half-way through. The size of the hopper varies, however, with the capacity of the retort bench, and it may hold anything from 4 to 8 tons. Immediately beneath the hopper is fixed a revolving drum divided into compartments by radial partitions. By means of a ratchet and pawl arrangement a continuous rotary motion is imparted to this drum, and the extent to which it is turned regulates the amount of coal falling through from the base of the hopper. On being discharged from the drum the coal falls into a special trough which enters the retort for a few inches. A hydraulic pusher ram with a plate attached to the free end then comes into operation and carries the coal charge into the retort. On the backward stroke of the pusher bar the coal drum is again revolved so that another charge is ready to be pushed forward on the next outward stroke. By means of a special stopper bar the distance into the retort travelled by the ram is reduced by about 18 inches on each stroke, so that the coal is distributed comparatively evenly along the floor of the retort. For an ordinary medium charge seven strokes on each side of the bench are necessary to complete the work, but with the modern heavy charge the stopper bars should preferably be removed so that the retort may be packed. The hydraulic power is conveyed to the machine by flexible wired hose pipe, and the working pressure varies between 400 and 600 lb. per square inch. The machines travel in front of the benches on a double-line track, and a special three-cylinder hydraulic motor is provided for this purpose. The total weight of a machine with hoppers filled is about 12 tons. Two chargers and one hydraulic pusher are capable of dealing with about 40 retorts per hour with charges of about 18 cwt. The capacity of the machines is, therefore, about 36 tons of coal per hour. It is difficult to give anything approaching exact figures for cost, but under normal conditions the machines, complete with

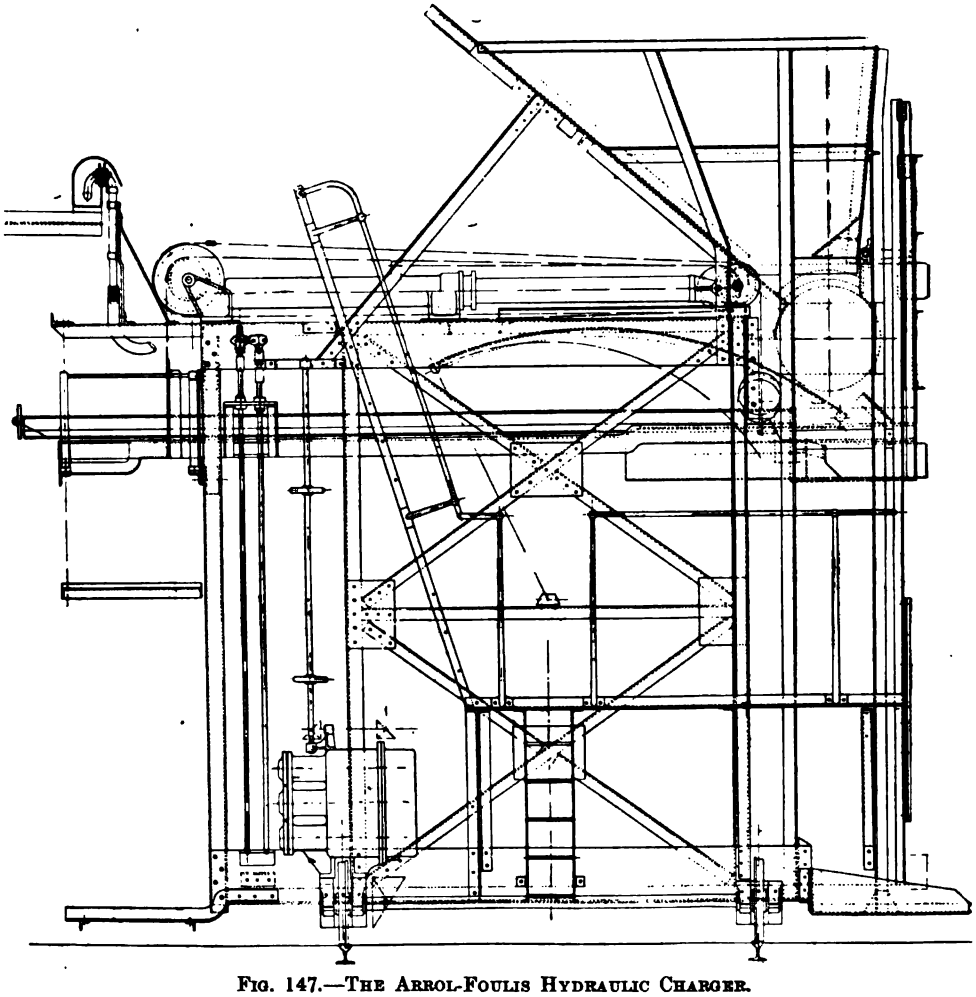


FIG. 147.—THE ARROL-FOULIS HYDRAULIC CHARGER.

piping for connecting up to the fixed mains in the retort house, could be obtained for £600 each.

THE HUNTER-BARNETT PUSHER

One of the first hydraulic pushers to be introduced was that invented about 1907 by Messrs. Hunter & Barnett. It is very generally employed in conjunction with the Arrol-Foulis charging machinery, and is most suited to this owing to the motive power being water. The whole machine is self-contained. The frame is formed of substantial mild steel plates and angles rigidly connected together and mounted on cast-iron brackets (*A*) which carry the traversing carriage wheels (*B*). A three-cylinder hydraulic motor (*C*) is fitted at the front of the machine and is geared to the carriage axles (*D*) by cast-steel bevel wheels (*E*). The method adopted

for pushing the coke through the retort is as follows :—A powerful telescopic ram (*F*) of hard, solid drawn, steel tube, provided with suitable pusher head (*G*) and fitted with internal drawback arrangement is used. The pushing head of the ram is water-cooled (*H*) to ensure that no undue heating may occur, and the ram works in a cylinder (*K*) of mild steel supported in cast-iron guides (*L*). These guides are mounted on a suspended beam (*M*) carried by chains (*O*) at front and back ends.

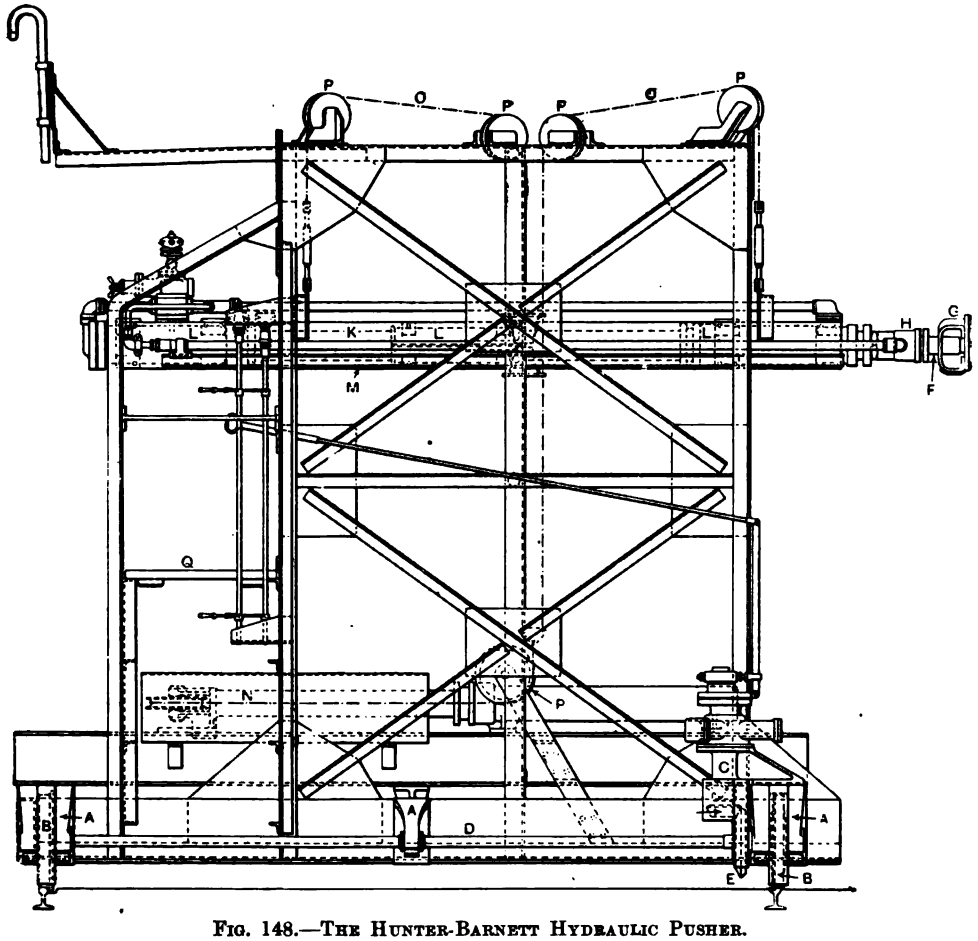


FIG. 148.—THE HUNTER-BARNETT HYDRAULIC PUSHER.

This suspended beam can be raised or lowered to suit the several tiers of retorts, the motions being obtained by means of a hydraulic ram (*N*) situated at the foot of the machine. The suspending chains (*O*) are carried over guide pulleys (*P*) to the points of support at the front and back of the beam. The beam is guided in the machine frame so that no side movement can take place. All the operations are practically automatic ; and a suitable platform (*Q*) is provided for the attendant, with all operating levers for valves and cocks placed in a convenient position within

his reach. The hydraulic pressure may vary from 400 lb. to 600 lb. per square inch, and the water is conveyed by a flexible armoured hose pipe sufficiently long to carry the machine over a number of beds of retorts. When the outreach of the pipe is attained, the hose connexion, as with the Arrol-Foulis chargers, is shifted to the next swivel joint on the main supply pipe and the machine carried on. Swivel joints are placed on the pressure main and are spaced to suit the length of the flexible hose pipe and adjusted to suit the particular arrangement used in the retort house. The cost of the machine, complete with piping for connecting up to fixed hydraulic mains in the retort house, is about £500.

The Williams-MacPhee Pusher

The Williams-MacPhee hydraulic pusher is one of the most recent of these machines introduced and comprises many commendable features. The simplicity of the entire arrangement is its chief recommendation. The machine consists of a pusher constituted of an outer cylinder containing two telescopic rams of sufficient

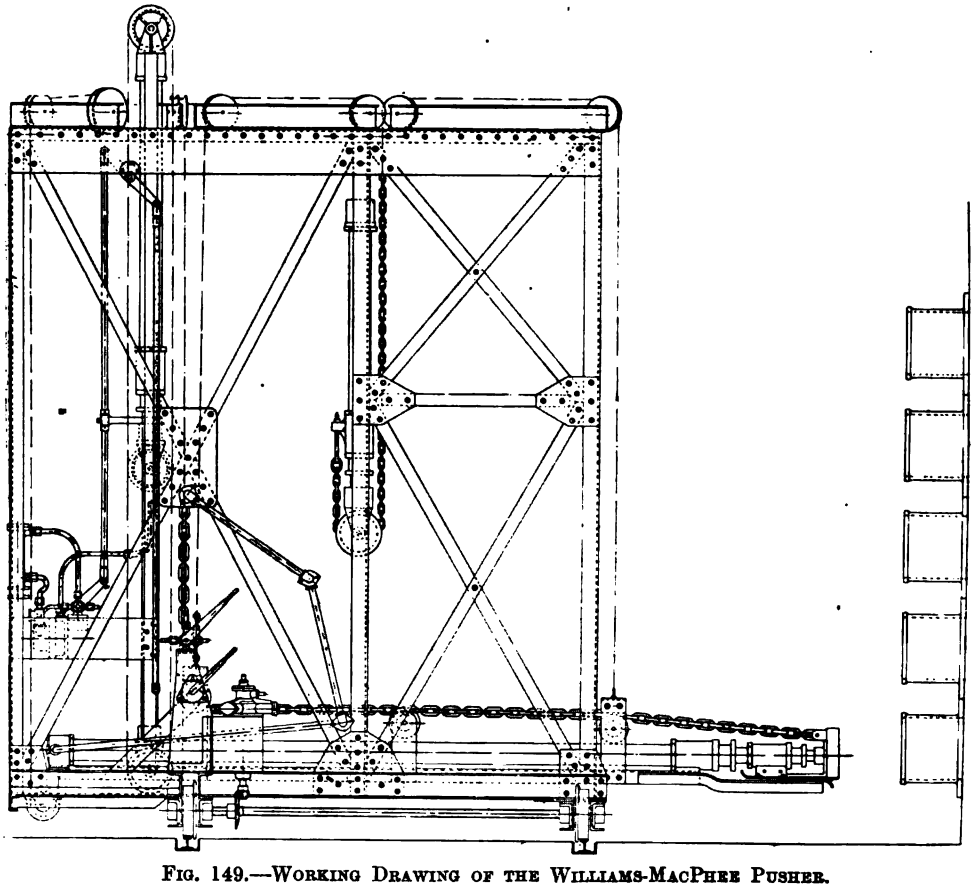


Fig. 149.—Working Drawing of the Williams-MacPhee Pusher.

length to extend through a 20-foot retort. Each ram is provided with a stopper at its rear end, and on the smaller solid ram a pusher plate, similar in shape to the retort but slightly smaller, is fitted. The ram is extended by admitting hydraulic pressure at the back of the cylinder, and by means of a special automatic return valve the pusher is withdrawn when the full extent of its stroke has been reached.

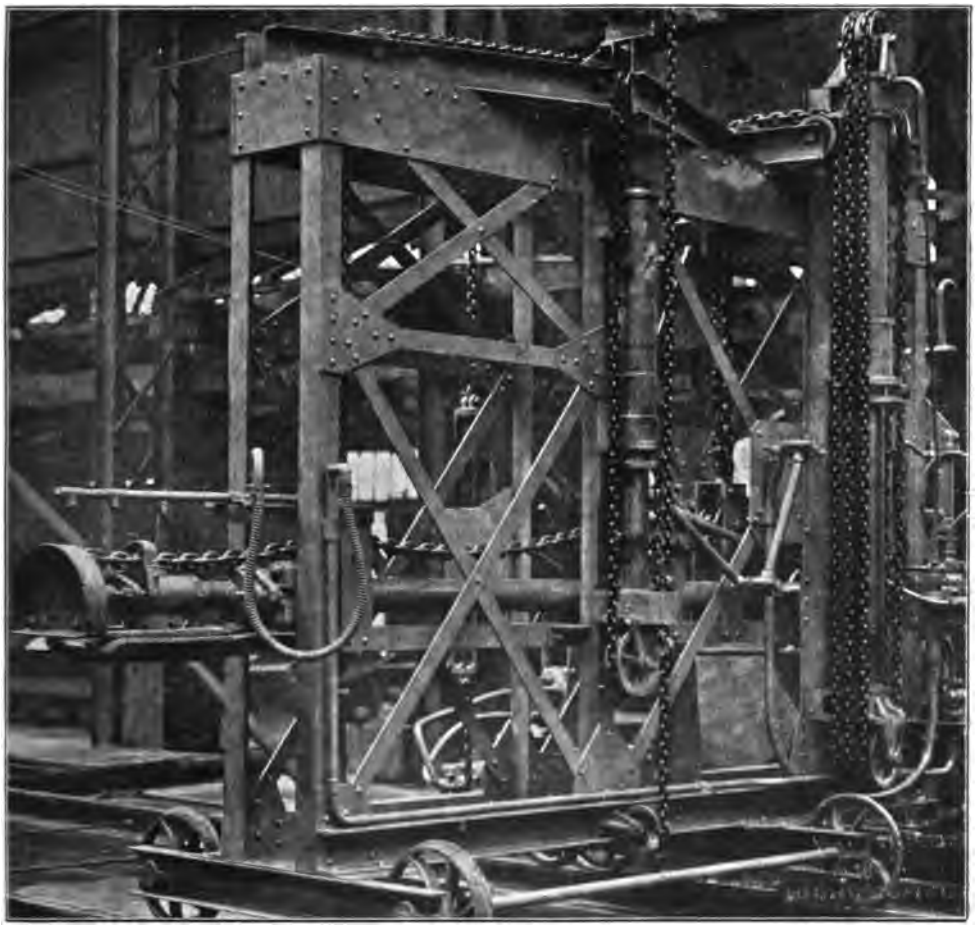


FIG. 150.—THE WILLIAMS-MACPHEE PUSHER.

Withdrawal is effected by a chain, attached to the pusher head, which passes around a pulley connected to a subsidiary hydraulic ram. This withdrawing ram is pulled into its cylinder by the tension of the chain during the outward stroke. The automatic return is arranged for by introducing a tappet rod connected by a lever to the distributing valve of a small actuating ram, the stroke of which reverses the controlling valve and opens the exhaust port to the pusher cylinder, thus withdrawing the telescopic rams. This tappet is engaged by the ram-head at a pre-determined

point on the outer stroke. In practice it is found that the outward discharging stroke takes about 10 seconds to be completed, whilst the return stroke is accomplished in 8 seconds. The chief merit of this type of pusher lies in the fact that there are only four glands to pack, whilst only one of them has to withstand the severe effects of entering the retort. The wear and tear is, in fact, almost inconsiderable, a pusher chain lasting for about twelve months before it has finally to be discarded. The cost of the machine, complete, is about £420.

The De Brouwer Stoking Machine

The first charging machine involving the projector principle was introduced by M. De Brouwer, gas engineer at Bruges. The outstanding advantage of this machine compared with others in use at the time was its ability to charge a full-sized retort from one side only, thus avoiding the necessity of installing machines on both sides of the bench. The whole apparatus is extremely simple, and consists of a steel frame carrying a large grooved pulley, three band pulleys for guiding a broad band, a driving motor, and a telescopic feeding shoot for coal. The principle of operation will be readily understood by reference to the line diagram (Fig. 151). The three band pulleys are arranged on the inside of the broad endless coal belt, and are so placed that this belt is made to take about a quarter turn round the large grooved pulley. The coal band bears on the two flat flanges of the pulley and causes the pulley to revolve at the same speed as the belt. The band is driven by ordinary belt drive on to the front band pulley from an ordinary shunt wound variable speed electric motor of 4 to 6 b.h.p., having a speed variation of from 750 to 1,500 revolutions per minute. Equally good results, however, may be obtained with compressed air motors or rope drives. The ordinary type of machine as now in general use is illustrated in Fig. 152. From this it will be seen that at the upper portion of the travelling framework there is a small hopper or measuring chamber into which the coal is fed from continuous hoppers erected in the retort house. A telescopic shoot leads from the measuring chamber to the groove of the large pulley, thus the delivery tundish for coal automatically adjusts itself as the machine is raised or lowered to the various tiers of retorts.

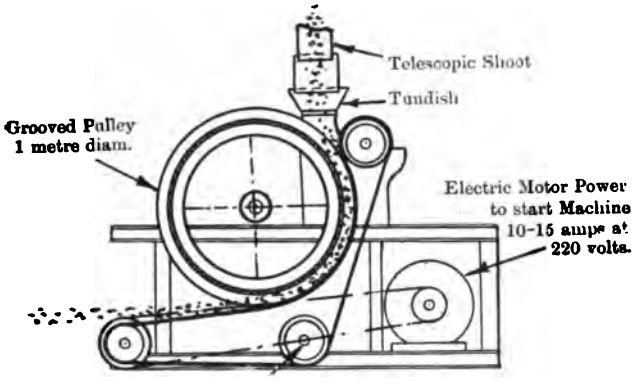


Fig. 151.—Line Diagram showing Principle of De Brouwer Projector.

The operation of charging is as follows:—Assuming that the overhead hopper is already full, the operator first starts the motor and moves the handle of his speed-regulating rheostat into the position necessary for giving the projector belt the

desired speed. This speed varies according to the length of the retort, the class of coal used, and the thickness of the charge required, and must first be found by trial. With ordinary broken coal and charges of about 9 cwt., the belt speed should be

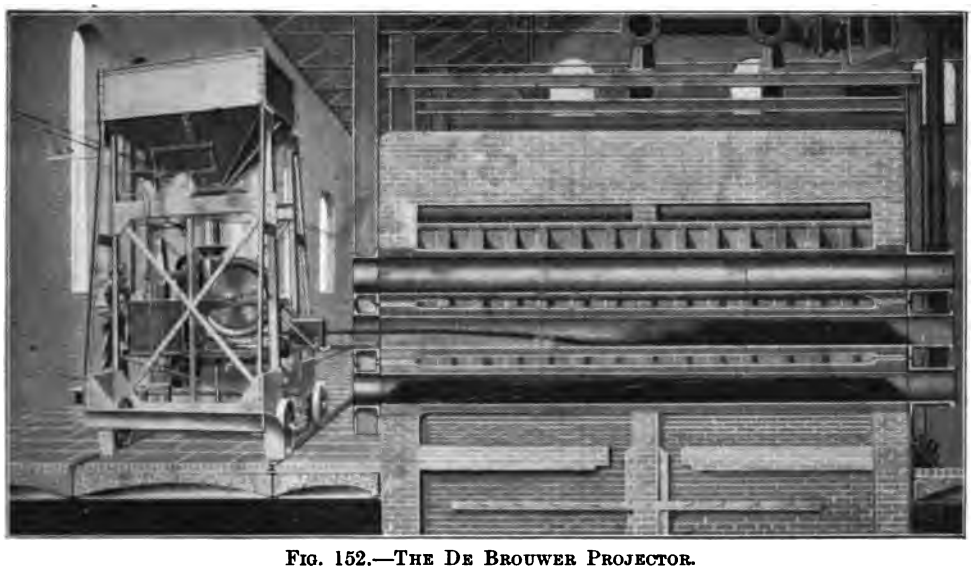


FIG. 152.—THE DE BROUWER PROJECTOR.

about 2,300 feet per minute, but for perfectly full charges a greater speed will be necessary. When the required speed has been attained, the hopper door is opened and the coal falls into the space between the belt and pulley. The centrifugal force exerted on the coal as the belt passes round the circumference of the grooved drum keeps the coal in contact with the belt, so that the velocity of the coal becomes the same as the velocity of the belt. As the coal reaches the front pulley the belt is suddenly deflected round the pulley, and the momentum keeps the coal travelling forward into the retort in a continuous stream. The distance through which the coal travels is gradually decreased as the operation of charging proceeds, this being effected by a gradual reduction in speed of the band. The whole operation of charging takes from 20 to 30 seconds, according to the amount of coal put into the retort.

FIG. 153.—SLANTING STOP FOR USE WITH PROJECTORS.

The earlier machines were suspended from an overhead carriage and traversed along by hand, but as this was a somewhat slow process the later machines were arranged in a travelling carriage or frame, and were driven by power.

With projecting chargers of this type some form of obstruction or stop is required at the further end of the retort to prevent the coal piling up on the cool mouthpiece. An ordinary piece of plate with a supporting rod at the back is generally used for the purpose. It is as well to remember, however, that the vertical stop originally employed frequently accounted for a small portion of coal remaining uncarbonized at the end of the distillation period, and it is preferable to make use of the slanting stop as seen in Fig. 153.

The following are the more interesting points connected with the De Brouwer machine :—

Large pulley : Diameter, 1 metre (39·3 inches).
Width on face, 15 inches.
Width of groove, 8 inches.
Depth of groove, $3\frac{3}{4}$ inches.
Average speed of pulley, 220 revolutions per minute.
Average speed of coal band, 2,300 feet per minute.
Power required, 10 to 15 amperes at 220 volts.

The cost of the machine, complete with wiring, is about £800, depending upon the number of tiers of retorts and the method of coal feeding.

The Jenkins-De Brouwer Pusher

This machine has a strongly braced framework of steel channels and angles, forming a travelling carriage, and is fitted with wheels for running along rails in front of the retort bench, preceding the De Brouwer charger. An electric motor and gearing box is fixed on the main channels of the frame, on the left-hand side, for hoisting the pusher ram to suit the various tiers of retorts and also for propelling the machine along the rails. The motor is of $7\frac{1}{2}$ b.h.p., entirely enclosed, provided with end covers, dirt and dust proof, and connected by a suitable coupling to the first motion shaft in the gearing box. The gearing box is fitted with a worm and worm wheel and spur gearing, also a clutch for connecting either the hoisting or propelling gear to the motor. One spur pinion in the gearing box gears with a spur wheel on one of the axles of the machine, and the worm wheel shaft carries a chain drum round which the hoisting chains work. These chains pass upwards from the drum, over pulleys on the machine frame, down again and round pulleys on the hanging frame carrying the telescopic ram, and back to a point near the top of the frame, where they are anchored.

The telescopic ram is in three parts, the first or inner length being formed of a strong mild-steel bar cut out of the solid and having drilled holes for the driving sprocket teeth and a plate end. The plate end carries a hood or scoop at the top to hold the coke and keep it from crushing up. This inner bar slides within the second length. Inside the front end of the second length is fixed a suitable stop which fits into a groove on the top side of the first length, so as to fix the length of stroke of the first bar and to ensure it having a rigid bearing within the second length when fully extended. The section of the second length is made up of two steel channels connected together by means of steel cover plates. This length has fitted at the

back end four rollers running on cast-steel pivots. The rollers are of suitable size for running within the channels which form the third length. The stroke of the second length is governed by stops fixed in the front end of the third length with which the front rollers come in contact, thus ensuring a rigid bearing when fully extended. The third length is of similar but larger section to that of the second length. This length is also fitted with four rollers running on cast-steel pivots. These rollers are of suitable size for running within the fixed channels which form the lower portion of the hanging frame, which is fitted with stops at the front end so that the third length also has a rigid bearing when at its extreme outward stroke.

On the underside, at the front end of the hanging frame, there is a steel rack

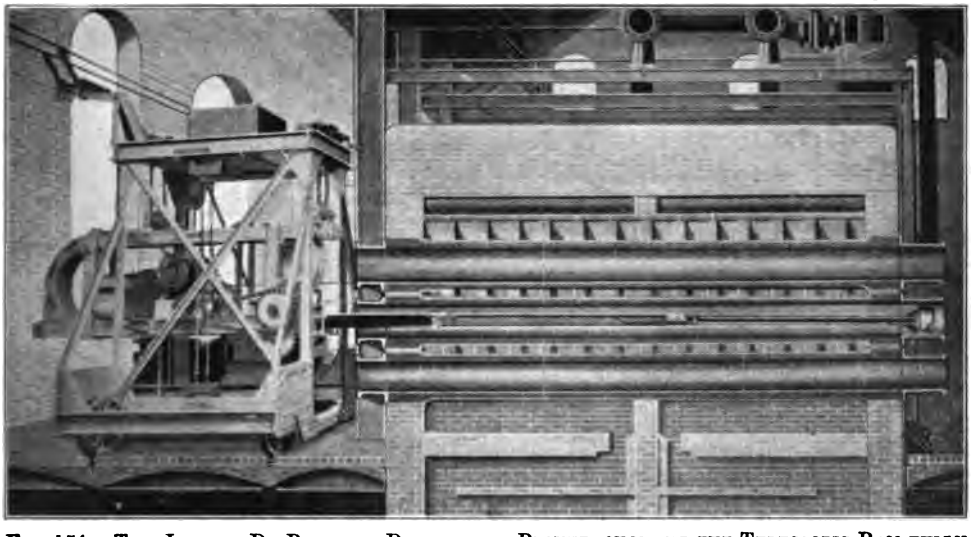


FIG. 154.—THE JENKINS DE BROUWER DISCHARGING PUSHER, SHOWING THE TELESCOPIC RAM FULLY EXTENDED.

pinion keyed to a shaft on the end of which is fitted a steel spur wheel to gear with a similar wheel on a shaft fixed above. To this latter shaft is keyed a strong sprocket chain wheel. The pinion gears in the rack forming the first bar and also gears with the second and third portion, consisting of cast-steel jointed links, which pass upwards round the guide path at the back end of the frame when the pusher bar is out of the retorts. A water spray is fixed at the front end of the hanging frame for cooling the telescopic ram.

Motion is transmitted from the pusher motor by means of a pinion driving a spur wheel keyed at one end of an intermediate shaft having at the other end a sprocket chain pinion for driving (by means of one of Hans Renold's patent roller chains) the chain wheel near the end of the hanging frame.

The telescopic ram is driven by an electric motor which is an exact duplicate of the hoisting and propelling motor, and which is carried on a cast-iron bedplate

bolted to the channels of the hanging frame. The current for the two motors is collected from two overhead bare copper conductors by means of two trolley poles fixed near the top of the machine frame. From these poles the current is led by means of stranded copper insulated conductors carried in steel conduits to the switch and connexion box on the platform. The connexion box is fitted with the

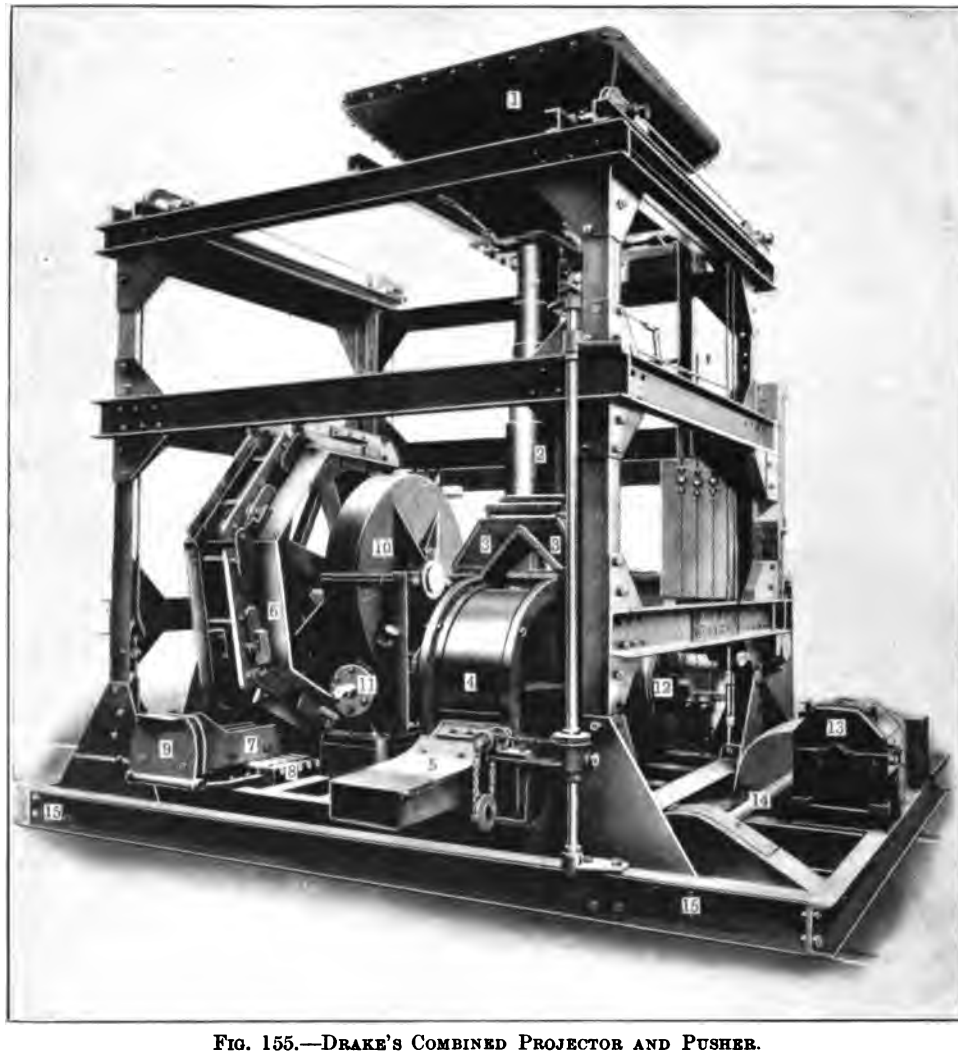


FIG. 155.—DRAKE'S COMBINED PROJECTOR AND PUSHER.

necessary double pole switch, automatic circuit breaker and distributing fittings From this box the current is led to the reversing controller of the hoisting and propelling motor and to two bare conductors strained vertically on one side of the machine frame. The motor driving the telescopic ram collects its current from these conductors by means of two short trolley poles fixed to the hanging

frame. An automatic cut-off is arranged so that the controller is returned to the "off" position at each end of the stroke of the ram, also when the hanging frame is moved to the top and bottom positions. A foot brake is attached to the machine for bringing it to rest exactly in front of the retort which is to be discharged.

The cost of the pusher is about £800, complete with wiring, but if combined with the projector on the same wheel-base the two machines may be obtained for about £1,150, depending upon the number of tiers in which the retorts are set.

Drake's Projector and Pusher

Drake's stoking machine, in which the projector and pusher are mounted on a common wheel-base, is illustrated in Fig. 155. The principle of the projector differs entirely from that of De Brouwer. The outer casing (4) contains a rotor very similar in construction to the paddle-wheel of a steamer, with the exception that

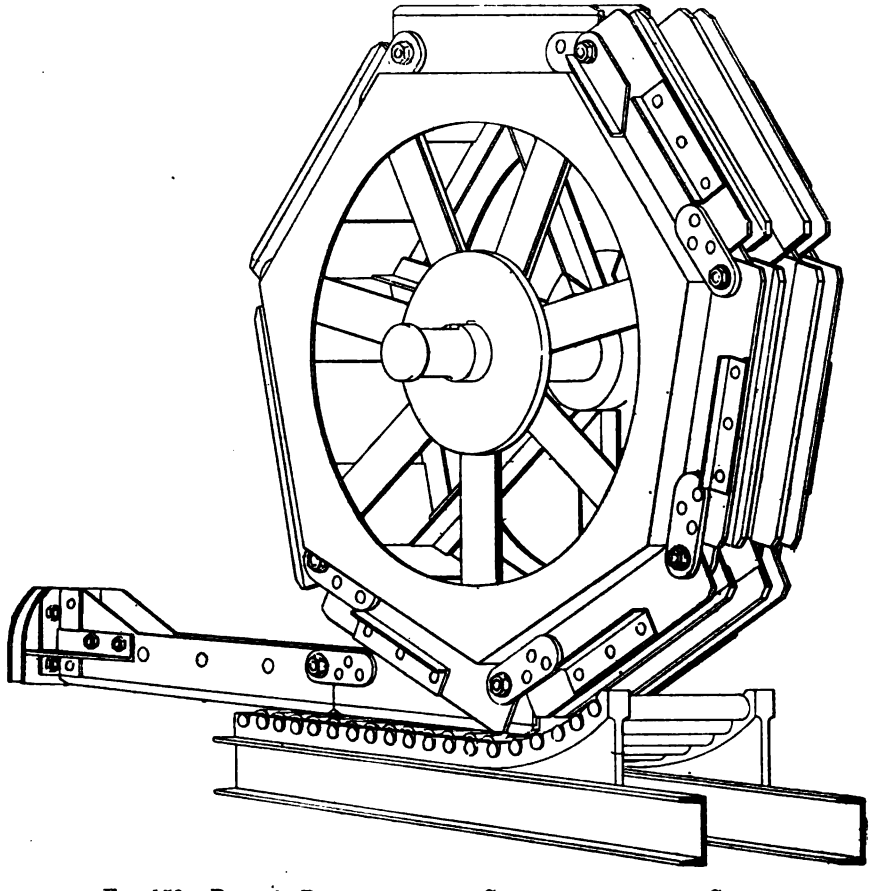


Fig. 156.—Drake's Pusher, showing Construction of the Chain.

it is divided down the centre so that with a feed at either side the coal is charged into the retort in two streams. These streams converge in the retort and form the charge. Owing to the manner in which the coal feed is arranged the lumps of coal are not knocked into the retort by the blades of the rotor, but they are picked up and thrown in by centrifugal force. It will be seen that the coal drops from a storage (1) hopper direct into a telescopic shoot (2) which in turn delivers to a breeches shoot (3) feeding into both sides of the projector simultaneously. An apron (5) is fitted to the front of the casing in order to prevent any spilling of coal.

The construction of the discharging pusher will be readily followed from Fig. 156. The ram is of taper construction, and the narrow end lets down into the wider end when folding round the drum. The chain is constructed from mild steel, and the links are fitted with renewable hard steel sliding pieces and hard steel horns. To one side of the shaft of the main drum is keyed a phosphor-bronze machine-cut worm wheel driven by a mild-steel worm running in an enclosed oil-bath.

Discharging Chargers

One of the most interesting modern developments connected with the operation of gas retorts is the discharging charger, which effects the expulsion of the coke and the refilling with coal in a single stroke. The first machine of this kind to be intro-

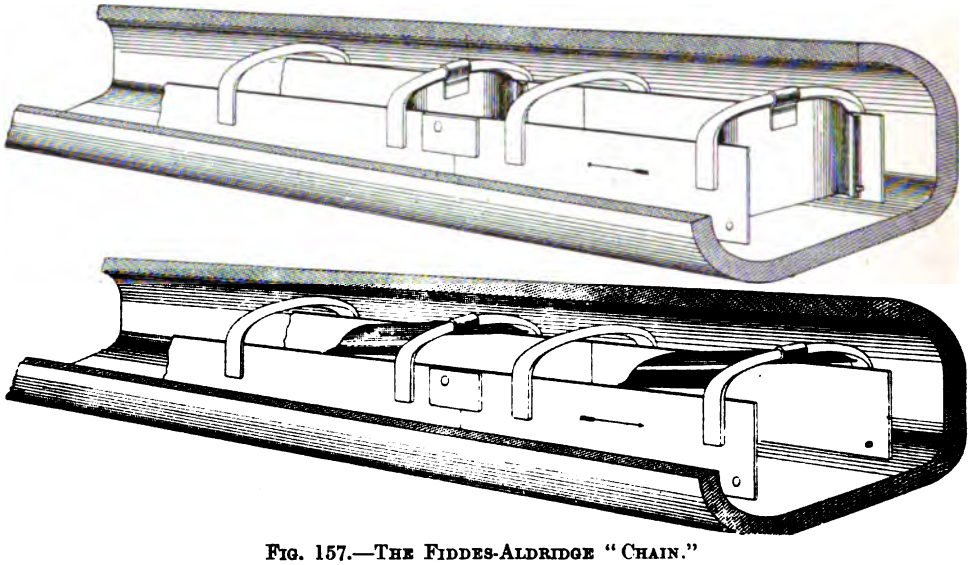


Fig. 157.—The Fiddes-Aldridge "Chain."

duced was the Fiddes-Aldridge, which accomplishes the work by means of a specially designed push-plate conveyor consisting of two vertical parallel plates but with no bottom. These plates are hinged about every 3 or 4 feet, and are maintained in position by cross-bars arched to the same radius as the crown of the retort. Plates

are suspended from the cross-bars, and are so arranged that when the conveyor or "chain" enters the retorts the plates remain vertical, but are free to lift when the chain is withdrawn. Each of the swinging plates pushes a certain amount of coal into and along the floor of the retort; whilst on the backward stroke the plates lift automatically and assist in levelling the charge. The construction and working of the chain will be clearly followed from Fig. 157.

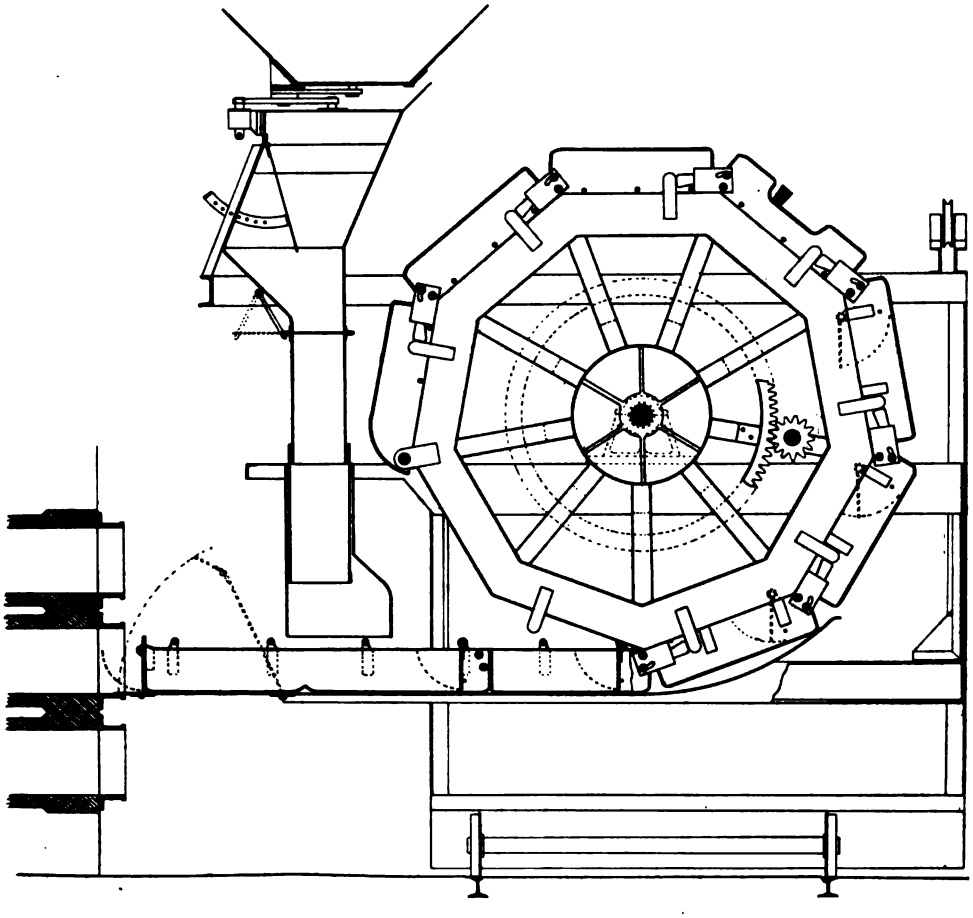


FIG. 158.—THE FIDDES-ALDRIDGE DISCHARGING CHARGER.

A measuring chamber over the chain receives the coal from continuous hoppers, the coal being dropped through a shoot into the chain as the latter passes forward into the retort. The chain passes round a vertical polygon wheel, which is usually driven by electricity, mounted on a steel framework. Two frameworks are provided (an inner one and an outer), the inner frame rising or falling inside the larger one so that any tier of retorts may be charged. A hinged apron plate is

lowered into the front of the retort mouthpiece, and acts as a connecting trough between the retort and the machine, the bottom of the apron plate forming the bottom of the chain. The front length of the chain (called the "fire-length") is very strongly constructed, and acts as a pusher head during the outward stroke. The operations of charging and discharging are performed simultaneously, about 30 seconds being necessary to empty and refill a 20-foot retort. The external dimensions of the machine are about 8 feet 6 inches long by 13 feet high. The standard pattern of the Fiddes-Aldridge machine is fully illustrated in Fig. 158, from which part of the framework has been removed so as to give a clearer view of the driving wheel and chain.

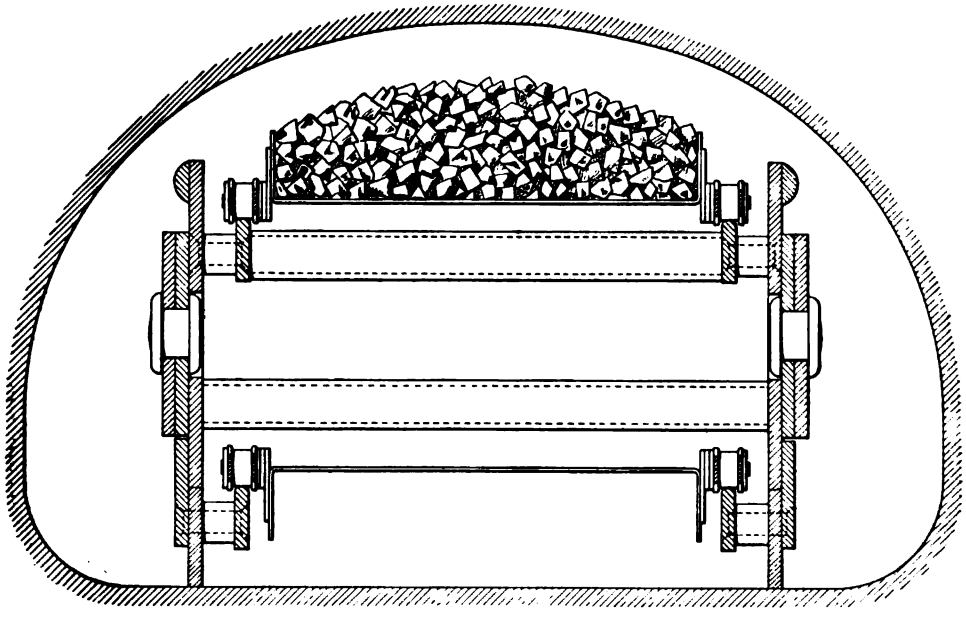


FIG. 159.—THE NEW TYPE OF FIDDES-ALDRIDGE MACHINE, FOR DELIVERING FULL CHARGES. (SECTION OF THE CHAIN.)

The machine was originally introduced at a time when many engineers still favoured the light charge of coal, and one of the few disadvantages it embraces is its inability to completely fill the ordinary retort with coal. This is due to the fact that a certain amount of room must be left in the crown of the retort for the return of the chain plates. In the latest type of machine, however, this drawback has been overcome, and retorts may now be completely filled if so desired. The main polygonal driving-wheel is still retained, and the modification has chiefly occurred in the construction of the chain. All push-plates are dispensed with, and instead there is a chain carrier inside which runs a flexible conveyor. The chain carrier and conveyor are set in motion and enter the retort together, the conveyor depositing coal along the bottom of the retort until the far end is reached. The speed of the

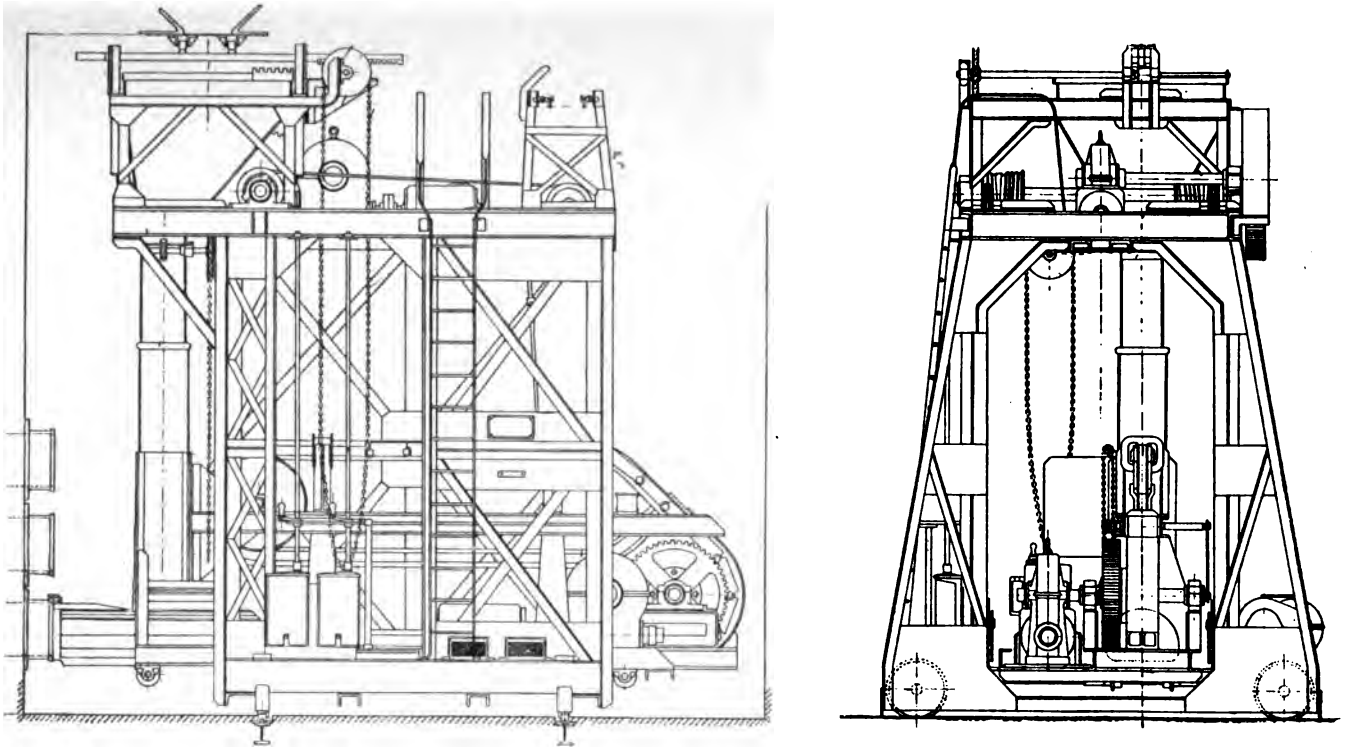


FIG. 160.—THE GUEST-GIBBONS DISCHARGING CHARGER.

flexible conveyor is then increased as both are withdrawn, and coal is thrown over the end of the conveyor at such a rate as to fill the retort completely. By varying the relative speeds of the chain carrier and the running chain or conveyor any sized charge can be placed in the retort. The flexible conveyor runs the full length of the carrier chain, so that there is in reality one conveyor inside another. As explained above, a thin layer of coal is laid on the bottom of the retort during the outward discharging stroke, but this is not essential, and, if so desired, the whole of the charge may be delivered over the end of the conveyor during the return stroke. The construction of the machine will be followed by reference to Fig. 159, in which the flexible and carrier conveyors are clearly seen.

The Guest-Gibbons Discharging Charger

This machine is one of those most recently introduced, and is capable of simultaneously discharging and charging a retort so that the fresh coal lies within about 5 inches of the crown of the retort. (The machine has recently been adapted to give a completely full charge.) The general construction of the apparatus is shown in Fig. 160. The portion of chief interest is the chain, which combines the coke pusher and means for introducing the charge. The coke is discharged by the pusher head on the outward stroke, when the position of the chain is as seen in Fig.

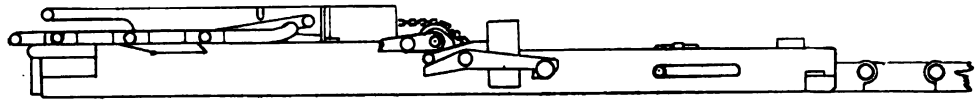


Fig. 161.

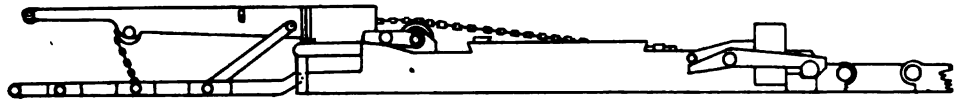


Fig. 162.

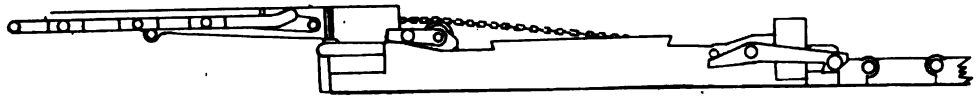


Fig. 163.

The Guest-Gibbons Chain.

161. The coal is then charged in by two or three strokes of the chain, according to the length of the retort. The coal, falling into the chain from overhead chambers, is carried into the retort by the drag bars and push-plate (Fig. 162). The chain is composed principally of two separate members, one inside the other, and when at rest on the machine is supported by a trough. The outer member carries the push-plate for discharging the coke, and the inner member supports at its front end an open grid or drag-bar upon which the coal is fed. A shutter at the bottom of the

feed shoot in the measuring chamber automatically cuts off the supply of coal to the drag-bars when a sufficient quantity has been taken for one stroke. The position of the chain during the backward stroke is indicated in Fig. 163. The tray plate connecting the machine with the retort is of similar size and section as the retort;

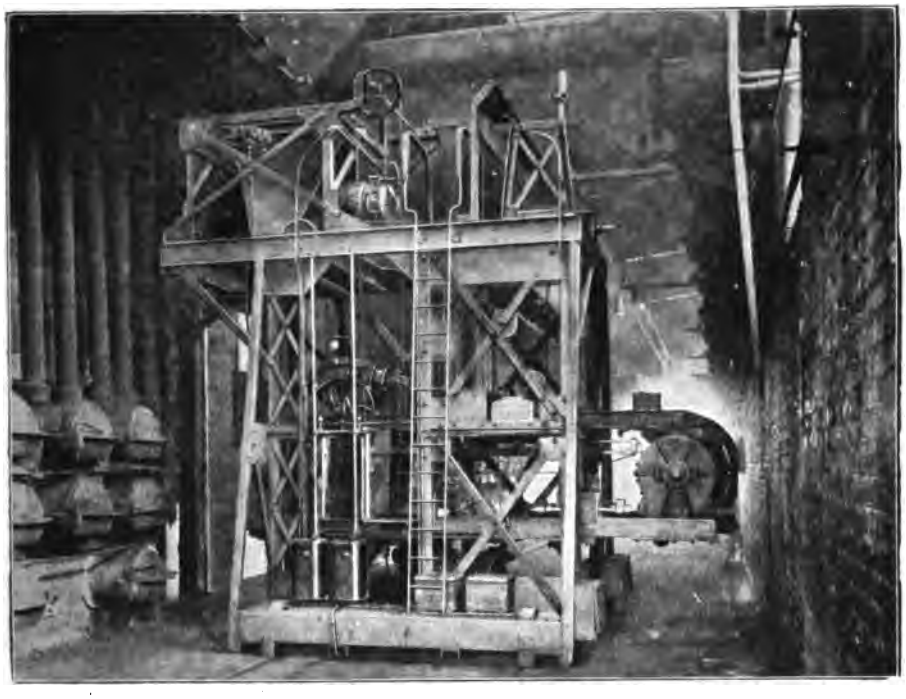


FIG. 164.—THE GUEST-GIBBONS MACHINE.

hence smoke and dust are to a great extent eliminated. Three electric motors are provided, one for each operation of hoisting, travelling, and charging. The time occupied for the complete operation of discharging and refilling is about 2 minutes. The cost of the machine, complete with wiring, is from £1,000 to £1,200, depending on the type and on the number of tiers in which the retorts are set.

SUBSIDIARY RETORT-HOUSE MACHINES

During recent years machines have been introduced into the retort house for performing subsidiary duties such as the augering of ascension pipes, the clinkering of producers, and the poking down of fuel into the latter. Owing to the comparative immunity from stopped pipes in the modern retort house, however, the augering machine has practically disappeared, but apparatus for performing the other duties mentioned seems likely to become a more or less essential auxiliary in the case of larger installations. With the introduction of the many forms of labour-saving machinery the gasworker is approaching a golden age as far as working conditions are concerned, and these latest machines may certainly be said to eliminate

the last remaining portion of gasworks labour in which considerable effort is entailed in the face of severe heat.

Clinkering Machines

The mechanical clinkering machine shown in Figs. 165 and 166 may be operated by hydraulic, pneumatic, or steam power, and effectively removes the heavy layer of clinker formed at the base of the fuel-bed in about one-fifth the time required with manual work. There is no particularly novel feature about its construction, which is on the principle of a ram, the head being designed to cut through hard masses of slag. The nature of the clinker collecting in a retort-bench producer varies to a considerable extent with the quality of the coal carbonized and the proportion of ash in the coke, and it is when inferior coals are in use that the machine is seen at its best. As an instance of the saving effected it may be mentioned that at one of the larger London gasworks a single fireman was capable of dealing with three producers during his eight-hour shift; that is to say, he was deputed to clinker retort settings yielding about half a million cubic feet of gas

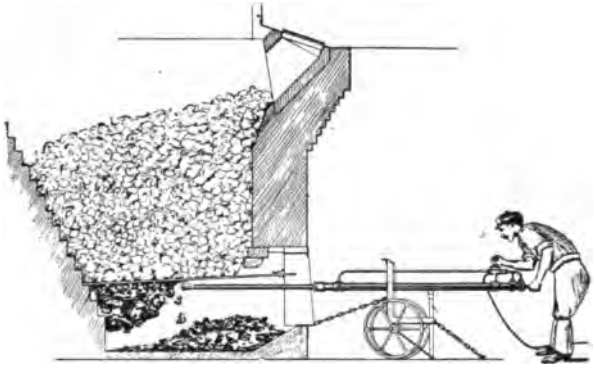


Fig. 165.—Mechanical Clinkering.

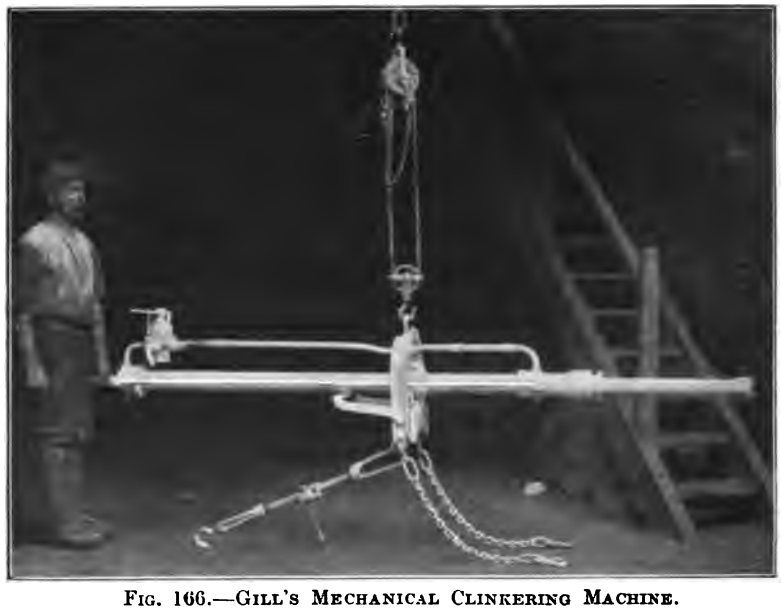


Fig. 166.—Gill's Mechanical Clinkering Machine.

per diem. With the aid of the machine the man increased his daily number of fires to eight, and his gas output to 1¼ million cubic feet. There are other attendant advantages, such as a saving of fuel, owing to the shortened period for which the doors are open, and decreased wear and tear on the false firebars.

The Furnace Poker

The object of this machine is to relieve the retort-house hands of a portion of their duties which demands much physical exertion. In the ordinary way the heated coke as it falls from the retort is poked down into the producer and levelled off by manual labour. For this reason it is customary to employ more men on the stage during the "firing draw" than is the case when the coke is merely pushed out and taken to the stock heap. By installing the poker the necessity for extra labour is averted, and the work can be more quickly and effectively carried out. The hydraulic type of machine is shown in Fig. 167. As will be seen, it is customary to attach

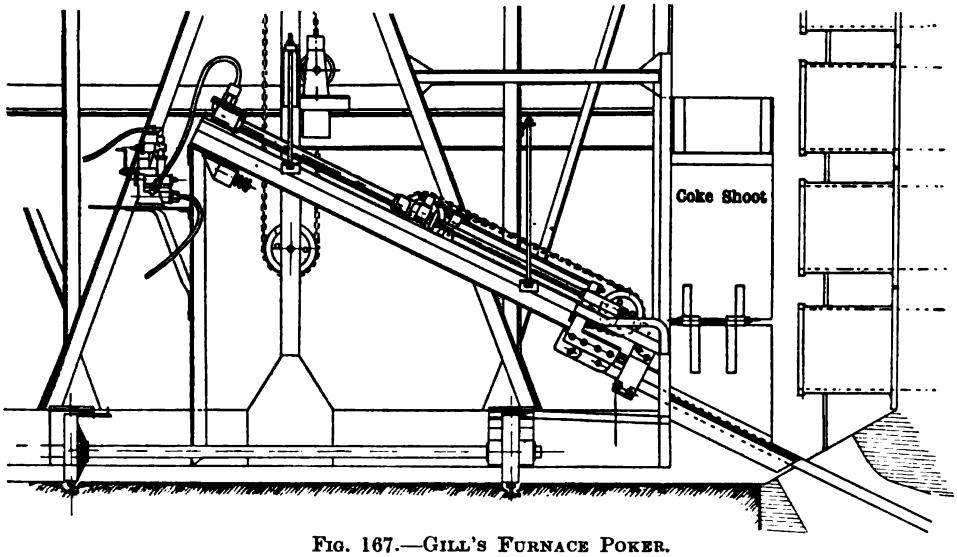


Fig. 167.—Gill's Furnace Poker.

the poker to the side of the framework of one of the "pushers," so that no separate travelling carriage is necessary. The poker itself consists of a rod 9 feet long by 3 inches wide by ⅝ inch in thickness, and is provided with a cast-iron fish-tailed head. It is actuated by two rams each about 4 feet in length and 1½ inches in diameter, attached by means of chains to a slipper fixed at the back end of the rod. One ram is used for the forward stroke and one for the backward stroke, the length of the stroke being 6 feet. The time taken to charge a producer with about 9 cwts. of coke is approximately 25 seconds.

COMPARATIVE COSTS OF RETORT-HOUSE LABOUR

It is only possible to draw a general comparison between the costs of operating retort houses under various conditions. Very much naturally depends upon the

magnitude of the installation, the proportion of the work which is carried out by mechanical means, and whether or not the men are worked up to their full capacity. A retort house may be fitted with the most economical type of charging and discharging machinery, and yet be served in a more or less primitive manner as regards the intake of coal and the disposal of coke. The methods of conducting the retort-house work may be classified under three headings :—

(1) Manual labour entirely, for all works up to about 20 million cubic feet per annum.

(2) Manual machines, for works between 20 and 120 million cubic feet per annum.

(3) Power machines, for works making more than 120 million cubic feet per annum. It should be noted that there are a limited number of works making less than this quantity in which power machinery is installed, but in general this limit may be adhered to unless exceptional considerations come into account.

For the purpose of comparison it is preferable to base the cost of labour in the retort house on the tons of coal handled, and in the following table the figures given include all items, *i.e.* the charges for taking in and breaking coal, wear and tear, charging and discharging, the disposal of coke and ashes, etc. :—

COMPARATIVE COSTS FOR OPERATING RETORT BENCHES

Hand charging and discharging.	2*s.* 6*d.* to 3*s.* per ton of coal handled (depending upon size of installation).			
"Manual" machines. . .	1*s.* 10*d.* to 2*s.* 2*d.*	,,	,,	,,
Power machines (older types) .	1*s.* 3*d.*	,,	,,	,,
Projector and pusher . .	1*s.* to 1*s.* 2*d.*	,,	,,	,,
Discharging chargers . . .	10*d.* to 1*s.*	,,	,,	,,
Inclined retorts . . .	1*s.* 2*d.*	,,	,,	,,
Vertical retorts (both types) .	4*d.* to 6*d.*	,,	,,	,,
Chamber ovens (Munich type) .	1½*d.* to 3*d.*	,,	,,	,,

ELEVATING AND CONVEYING MACHINERY

Only in exceptional cases is the gasworks engineer in a position to design in detail mechanical plant for the handling of his materials, and as there are to-day many contractors who are specialists in this type of work there should be no hesitation in placing the matter in their hands. If this is done, standardized details will not be departed from, and the system will gain in efficiency and economy. In obtaining tenders or settling upon new plant there are several points which the engineer with the erection of machinery in view should bear in mind. He should supply to the contractor figures showing the capacity of plant in tons per hour, stating the conditions of working. In return, the contractor should be asked for the following particulars :—

(*a*) Breadth of elevator buckets or conveyor band.

(*b*) Pitch of buckets, and speed of chain or band. The engineer should provisionally fix the speed, laying down a certain limit.

(*c*) Detailed specification of buckets and chain ; or,

(*d*) Detailed specification of belt.

(*e*) Particulars of arrangement for taking up elongation of the chain or belt, and the facilities afforded for the renewal of working parts.

(*f*) Details of framing and supporting girders, with the thickness of all sheets and plates in hoppers, etc.

[1](*g*) Power required for driving; also types and sizes of motors or engines supplied, and surplus power provided.

(*h*) Arrangements for lubrication; also what provision is made for the lessening of friction.

(*i*) If electrically driven, details of cabling, starters, and accessories (if any) supplied.

No general rule can be laid down as to the limiting size of a works on which coal or coke-handling plant can be profitably employed. It may be taken, however, that a minimum size plant (including buildings) would cost from £1,500 to £2,000; and 16 per cent. on this outlay represents about £300. Accordingly a 60 million per annum works would have to save 1*s.* 2*d.* per ton of coal used before the machinery could be shown to be profitable.

There is a certain similarity between elevators and conveyors in that, so far as types employed on gasworks are concerned, they consist almost solely of endless belts or chains passing around two terminal pulleys. To such chains are attached suitably shaped buckets or draw-bars. The length of the conveyor or elevator is measured from centre to centre of the terminal sprockets. It is the common practice to construct chains for these purposes from malleable-iron or steel links; and, as after a certain period of working the metal takes up a permanent stretch, it is usually necessary to provide some form of automatic tightening gear. With the simple elevator it will generally be found sufficient if the bottom sprocket is fitted with adjustible bearings, so that any extension may be periodically taken up. For elevators of larger capacity a single chain is insufficient, and multiple strands have to be resorted to. An objection to these is that the different strands (usually two) will stretch unevenly, thus throwing the buckets out of alignment with one another. This particularly applies to the malleable-iron type; and in long lengths of conveying machinery it is usual to provide some form of adjustment to alleviate the defect,

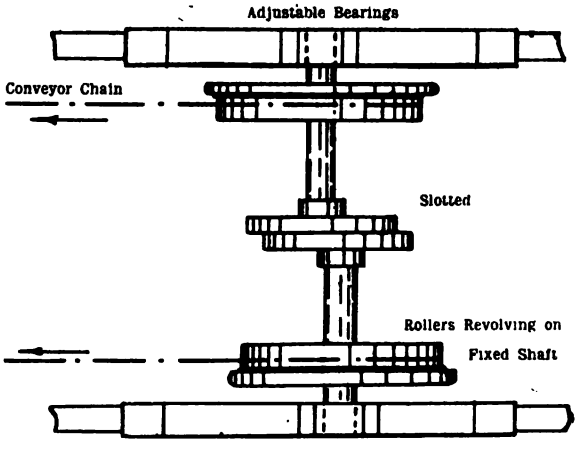


FIG. 168.—CHAIN-TIGHTENING DEVICE.

[1] The engineer will generally prefer to purchase his own motors, arranging for the surplus of power he thinks advisable.

distinct from that employed for automatically taking up any slack. The device for tightening each chain which is employed in many conveyors is shown in Fig. 168, whilst Fig. 169 illustrates the means introduced for taking up the total increase of length of the chain. In modern elevators for heavy purposes wrought-iron links connected together by turned bolts passing through machine-bored holes are almost exclusively employed.

On gasworks, the principal materials requiring transport from one point to another are coal, coke (either hot or cold), clinkers, and in some cases oxide of iron, lime, and such-like materials. It is chiefly, however, materials of moderately high density which have to be considered. This fact is of importance in that it has an important effect upon the angle of slope of the elevators. Machinery dealing with vegetable matters of low specific gravity can be driven at very much higher speeds than that made use of for such substances as coal. Elevators for coal, moreover, must be inclined so that part of the load is borne by the rubbing strips attached to the guide supports. The whole weight is not then hanging from the driving sprocket, as is the case with the vertical elevator. For heavy materials the angle of slope (with the horizontal) should lie between 45 and 60 degrees, although many gasworks elevators are erected at so great an angle as 70 degrees, or in some cases vertically. The speed should not exceed 130 feet per minute under any circumstance. In the De Brouwer combined hot coke elevator and conveyor the normal working speed is in the neighbourhood of 40 feet per minute, and the angle of slope is usually no more than 30 degrees with the horizontal. It is necessary to bear in mind that when a friable material such as coke is being dealt with the speed of an elevator of the bucket type should be low, because a high velocity of delivery entails considerable breakage of the material, in addition to curtailing the life of the receiving shoots. In general, it may be said that coke elevators should not be operated at a greater speed than 60 to 90 feet per minute. Capacity, usually based on tons delivered per hour, depends, of course, largely on speed, but also upon the size and pitch of buckets, or —in the draw-bar types—upon the depth, width, and pitch of the bars.

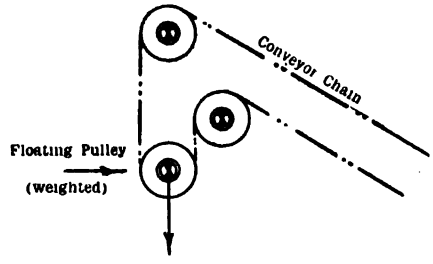


FIG. 169.—COMPENSATING DEVICE FOR TAKING UP SLACK IN DRAW-BAR CONVEYORS AND DRIVING CHAINS OR ROPES.

With bucket-conveyors much depends upon the extent to which each bucket is filled. Where average practical conditions are considered, the following formula may be taken as a useful guide to capacity:—

$$\text{Capacity} = \frac{S \times B \times W}{96{,}768 \times P} \text{ tons per hour.}$$

where B = Capacity of buckets in cubic inches.
S = Speed of conveyor in feet per minute.
W = Weight per cubic foot of substance carried (*see* page 240).
P = Pitch of buckets in feet.

Band Conveyors

Band or belt conveyors have attained a certain degree of popularity on gasworks, and for conveying the lighter materials, such as oxide of iron or sulphate of ammonia, they are probably to be preferred to other types. For such materials less power is required by a band conveyor than by any other, and the speed may run up to as much as 600 feet per minute. For heavier substances, such as coal and coke, the whole design must necessarily be of a much stiffer nature, whilst the band itself must be considerably stronger in order to take the greater weight imposed upon it. It is not generally realized that when used for coals the centre of the band, and not the outside edges, shows the greatest tendency to wear; consequently the middle portions of the width require special care in their preparation. In a general way, leather material as used for ordinary driving belts is to be avoided, and the band is preferably composed of special insertion covered with india-rubber where it comes in contact with the rollers or guides. The upper portion which carries the load should be made from solid india-rubber, which may be reduced in thickness towards the edges. Canvas or balata is often used.

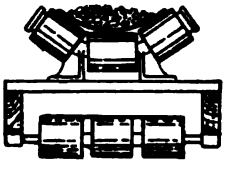


Fig. 170.—Band Conveyor with Troughed Leading Portion.

There are two main types of band conveyors, namely, those in which the leading and return portions of the belt pass over parallel guide rollers so that throughout its travel the belt is perfectly flat, and those in which the rollers are so arranged as to cause the leading portion of the belt to assume a trough-like shape (Fig. 170).

The speed of band conveyors depends largely on the weight of the material to be conveyed, but also to a considerable extent upon the size of the lumps. So far as the last-named factor is concerned the rate of travel should vary in inverse ratio to the size of the pieces; hence large lumps must travel more slowly than smaller ones. Under normal conditions the speed for coal purposes will be from 150 to 300 feet per minute, although with fine coal this may be increased up to 400 feet per minute. The following table, compiled by Zimmer, gives an indication of the capacity of these elevators and the horse-power required to drive them. The author, however, is of the opinion that the speed given (600 feet per minute) is too great, the maximum figure for capacity too liberal, and the B.H.P. for wider buckets not adequate.

Speed and Capacity of Band Conveyors for Coal

Width of band.	Speed.	Capacity.	Size of coal.	B.H.P. for 100 feet length of conveyor.
Inches.	Feet per min.	Tons per hour.		
12	150 to 600	10 to 35	From 2-inch to dust	3·2
18	,,	50 to 175	,, 4-inch to ¾-inch	4·8
24	,,	125 to 475	,, 6-inch to 1-inch	6·0
30	,,	250 to 900	,, 7-inch to 2-inch	7·6
36	,,	350 to 1,500	,, 9-inch to 2-inch	9·2

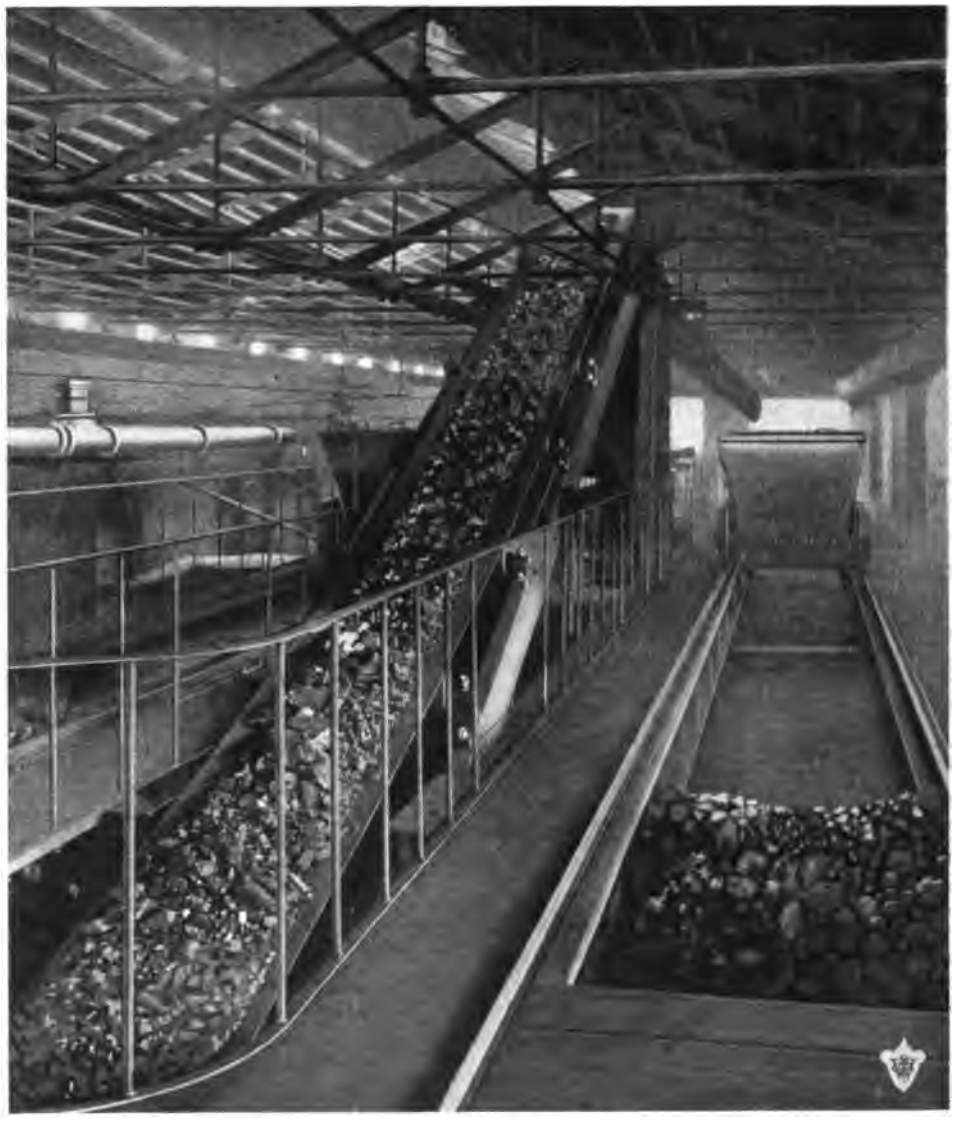


FIG. 171.—BELT CONVEYOR FOR COAL.

Band conveyors need not necessarily be operated on the level, but can also be used for elevating purposes. When conveying up-hill, however, the inclination should not be greater than 25 degrees, otherwise their capacity will be reduced by slip. When the band is inclined the power necessarily increases in accordance with the height through which the load is raised. One of the chief advantages attached to this type of conveyor is that it does not injure in any way the material on which it is working.

There are many other types of conveying machinery in more or less general use on gas-works, the following being the more important systems :—

(*a*) The travelling-tray conveyor.
(*b*) The swinging-tray conveyor.
(*c*) The push-plate conveyor.
(*d*) The gravity-bucket combined elevator and conveyor.
(*e*) Telphers.

Tipping or Travelling-Tray Conveyors

Band conveyors are not wholly suitable for conveying substances of a heavy or abrasive nature, on account of the injury caused to the material forming the belt. Owing to the advantages they offer, however, conveyors embracing the principle of the band are frequently preferred by many engineers, and the travelling-tray conveyor, whilst disposing of the perishable belt, retains the desirable features of the system. Figs. 172 and 173 illustrate one of the best known types of travelling-tray conveyors. This type of conveyor consists essentially of an endless chain to which are attached a number of overlapping trough-like sections. The chief objection to the employment of these conveyors is their inability in many cases to deliver at intermediate points in their length. In the type illustrated, however, a special tip-up bar enables the conveyor to deliver at any desired point in its course, or at several points simultaneously, as well as over the extreme end. By a simple modification, moreover, the material can be carried up a gradient much in excess of the limiting angle of the material on the trays. In discharging a friable material such as coke over the end, the drop is minimized by the preceding tray intercepting the fall of material from the tray following it. The power required is low in comparison with types of conveyors such as the push-plate, and is usually under 5 per cent. of the weight of the moving parts.

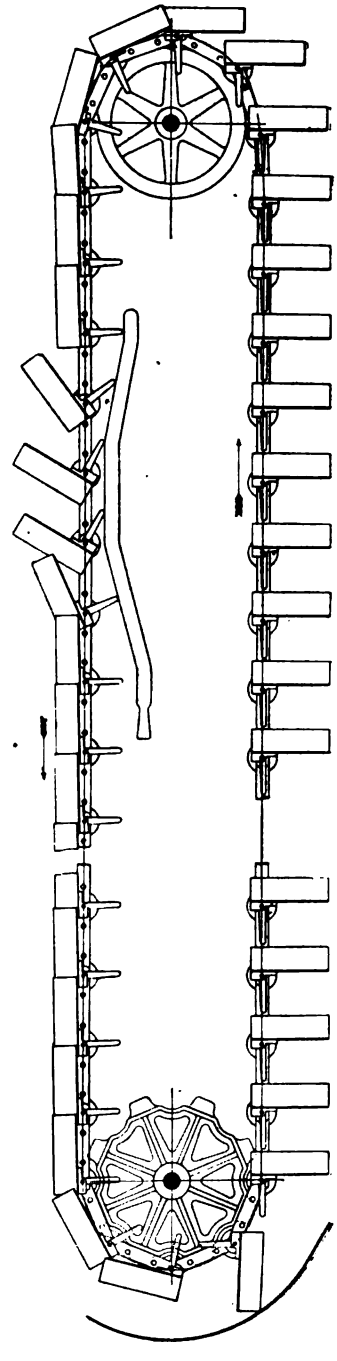


Fig. 172.—Diagrammatic Arrangement of Babcock & Wilcox's Tipping-Tray Conveyor.

About 250 feet of conveyor carrying 20 tons of material per hour can be worked with one indicated horse-power. When the conveyor is required for use as an

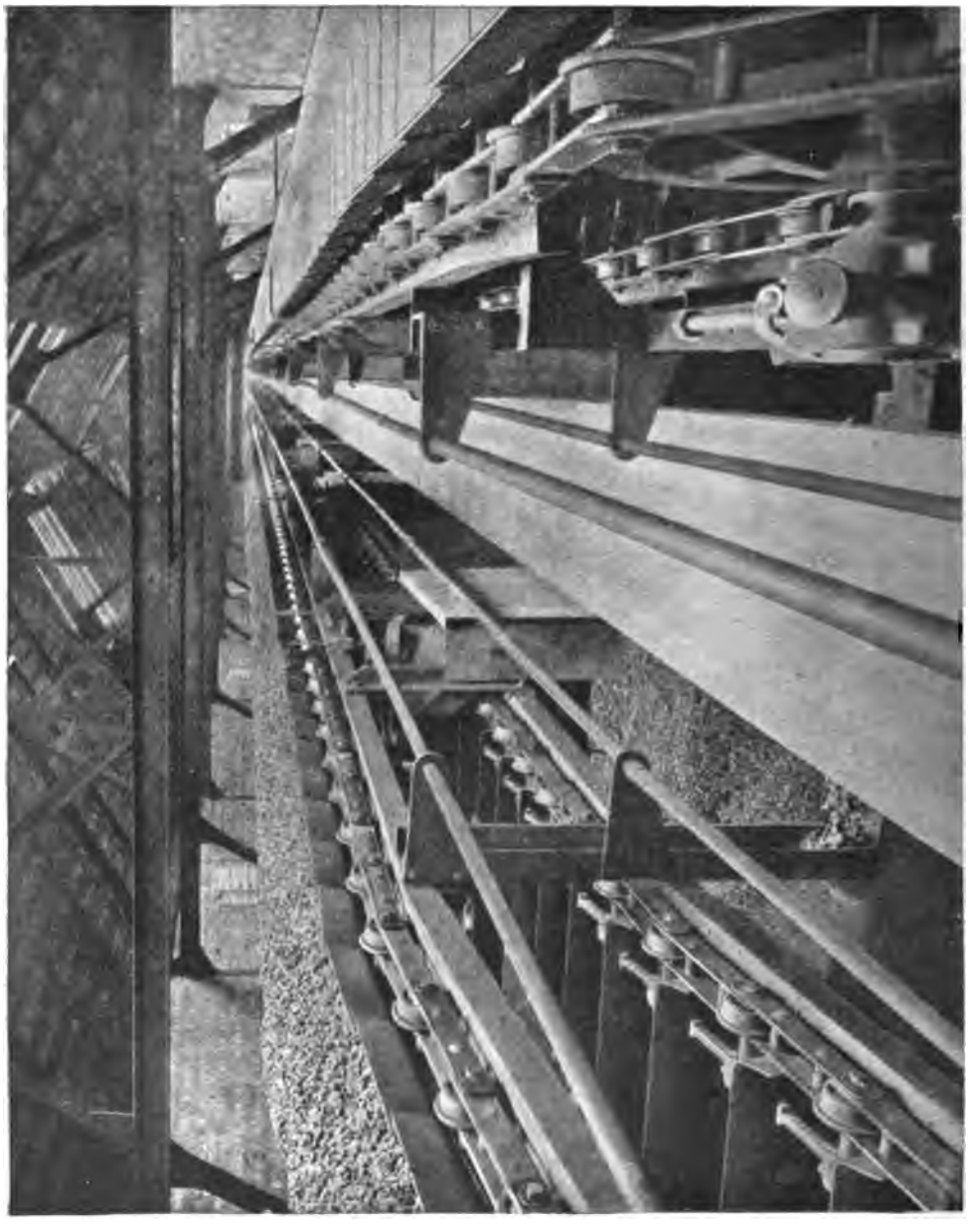


FIG. 173.—A TIPPING-TRAY CONVEYOR INSTALLATION.

elevator back lips are applied to the trays. The normal speed of travel is somewhat less than with push-plate conveyors, and varies between 60 and 120 feet per minute.

Push-plate Conveyors

A typical form of push-plate conveyor is illustrated in Fig. 174. Each push-

Fig. 174.—Push-plate Conveyor. West's Type.

plate, it will be seen, has a projecting axle at either end to which special rollers are attached. The push-plates are secured by special chain attachments, and discharge

outlets with side doors are fixed at convenient intervals. Conveyors operated on this principle may be arranged with either a single or double chain, but in any case the push-plates should not be allowed to touch the bottom of the trough. For this reason, in those designs where guided rollers are not made use of, the plates are fitted with some form of skidder-bar which slides in its guides and takes the greater portion of the wear. So far as economy in motive power is concerned the roller types are to be preferred. The normal speed of these conveyors is somewhat greater than that of the tipping-tray type, and varies between 60 and 180 feet per minute. The capacity depends upon the speed, the size of the trough, and the pitch of the draw-bars. The pitch may be anything from 18 inches to 3 feet. With the usual trough of about 2 feet in width and having push-plates at a pitch of 2 feet the capacity is normally 30 tons per hour, with an average speed of 100 feet per minute. Conveyors of this type have been somewhat generally adopted for the removal of hot coke from retort houses. When used for this purpose it must be borne in mind that the friability of the coke will not permit of a high rate of travel, if disintegration of the material is to be avoided. In the De Brouwer conveyor the average rate of travel does not exceed 40 feet per minute.

Gravity-Bucket Conveyor

The gravity-bucket or travelling-bucket conveyor has for some years been a foremost favourite in America, and is now assuming some considerable importance in this country. Briefly described, it consists of two endless chains held apart at

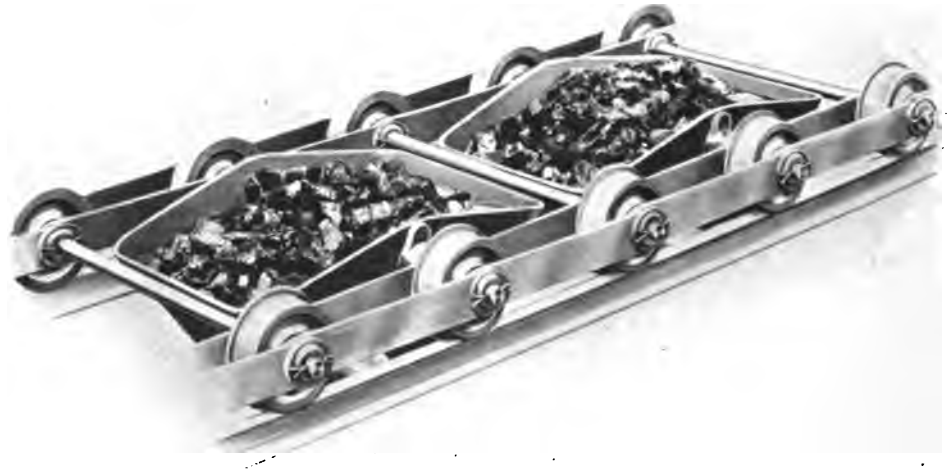


Fig. 175.—The Gravity-Bucket Conveyor.

a pre-determined distance by suitable bars, to each end of which is fixed a small roller, these rollers running along special guide-tracks. The distance pieces between the chains are fitted with buckets which are suspended from a point above their

centre of gravity, and are free to swing. Thus, whatever the position of the endless chain, the buckets always hang in an upright position whether they are travelling vertically or horizontally. For this reason the gravity-bucket system may be employed to perform the combined duties of elevator and conveyor. Delivery at any desired point is arranged for by interposing a device which tilts the bucket and discharges its contents. The driving gear is unique, and usually consists of a spur-geared engine operating two sets of panels which successively thrust the chain in the direction of its travel, engaging with both sides simultaneously. In this way the chain is pushed forward link by link. An essential feature of the system is the provision of some type of filling device, so that the material may be delivered to the buckets without undue spilling. The filler consists of a hollow casting securely keyed on a steel spindle. The casting is formed with five openings in its periphery, and these are arranged to centre with the buckets as the filler is rotating. The filler is driven direct by the conveyor chain engaging with an adjustable sprocket wheel bolted on the rotating hollow casting. The speed of the gravity bucket is necessarily low, the rate of travel normally varying between 25 and 50 feet per minute. The capacity depends upon the size and speed of the buckets used, and installations may be erected capable of handling from 20 to 100 tons and upwards per hour. The power required is low in comparison with many other types of conveyor, but depends largely upon the proportion of elevating work which is performed (*see* page 224).

Hot-Coke Conveyors

Owing to its hard, gritty, and abrasive nature coke is a very different material from coal with which to deal, and unless the apparatus used for handling it is suitably designed the wear and tear is very great. This is particularly the case when the highly heated coke has to be dealt with as it is discharged from the retorts. At the present day there are two principal methods of dealing mechanically with hot coke :—

(1) By means of conveyors of the push-bar or travelling-tray types.

(2) By means of transporters or telphers.

Each method has its particular advantages, and the question as to which shall be adopted must be decided entirely by local conditions and requirements. In many cases a combination of the two types is the ideal arrangement, a conveyor being used inside the retort house and a telpher outside in the coke yard. Telphers are not solely confined to dealing with coke, and are now extensively used for coal transportation as well, whilst in medium-sized works the combined duties may be carried out by the one machine. The principal advantages of a telpher plant are the amount of ground which can be covered without an excessive expenditure and the small amount of handling received by the coke, with a corresponding decrease in the production of breeze. Telphers in general are cheaper than hot-coke conveyors, and the latter are certainly offenders with regard to breakage of coke. The great advantage of the conveyor, however, is that it is continuous in action, and, therefore, does not restrict the speed of the stoking machinery. Moreover, when once started to work it is practically automatic in action, and does not require a man in constant

attendance as does the telpher. The cost of upkeep of the telpher is light in comparison with conveyors.

The De Brouwer Hot-Coke Conveyor

This type of hot-coke conveyor (illustrated in Fig. 176) has probably been adopted more extensively than any other system, both in this country and on the Continent. On English gasworks alone more than seven miles of the conveyor are in operation. The conveyor consists of a trough of varying width and depth, to suit the quantity of coke to be dealt with, in which the chain slides. This trough usually consists of a $\frac{1}{4}$-inch or $\frac{3}{8}$-inch steel bottom plate with steel channels or angles riveted along each side, the joints being made so as to form a watertight pan in which are placed cast-iron renewable bottom plates. These bottom plates are about $\frac{5}{8}$-inch

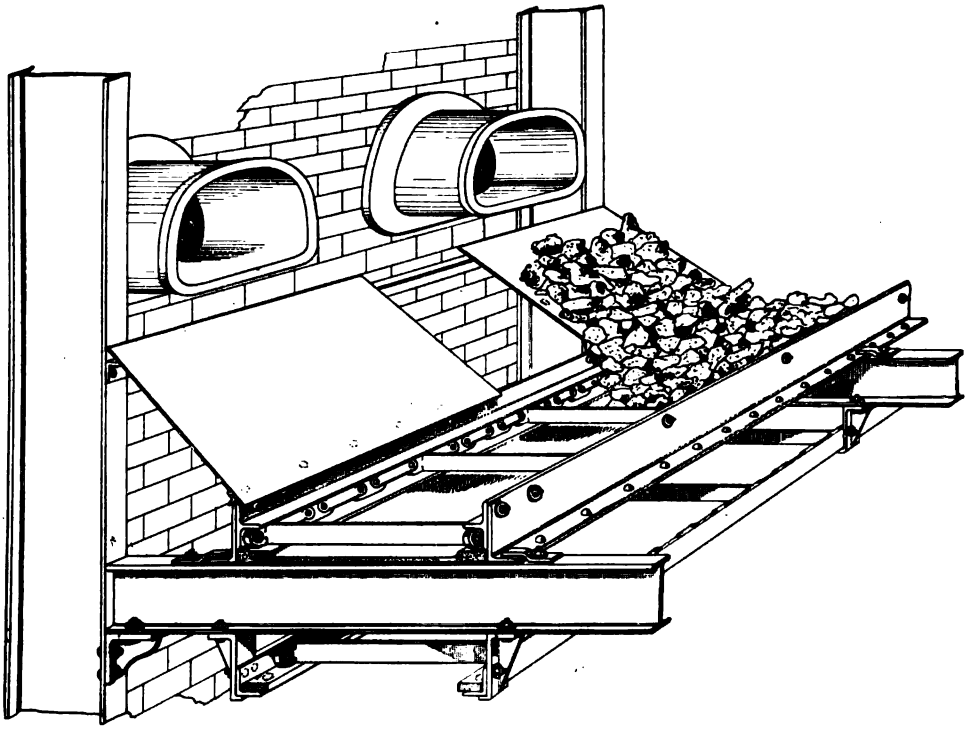


Fig. 176.—The De Brouwer Hot-Coke Conveyor.

thick in the middle with raised paths $\frac{5}{8}$ inch deep on each side for the chains to slide upon. The chains are protected by steel angles or tees bolted to the trough sides with special countersunk headed bolts. The sides of the trough are protected by $\frac{1}{2}$-inch steel renewable plates which are bolted on with countersunk headed bolts. These plates also hold the cast-iron bottom plates in position. In some cases the trough in the retort house is covered over with hinged doors of $\frac{1}{4}$-inch or $\frac{3}{8}$-inch steel

chequered plate, level with the floor, the doors on the retort bench side being used to deflect the coke from the retorts into the trough. After leaving the retort house the conveyors usually rise at an angle, varying with the space available, to a suitable height for delivering the coke into hoppers, etc. In these cases the trough up the slope is made about 2 feet deep by means of $\frac{1}{4}$-inch steel side plates and is covered by $\frac{3}{16}$-inch steel plates bolted on the top, thus completely enclosing the trough and carrying the steam from the quenching to a steel chimney near the top of the incline.

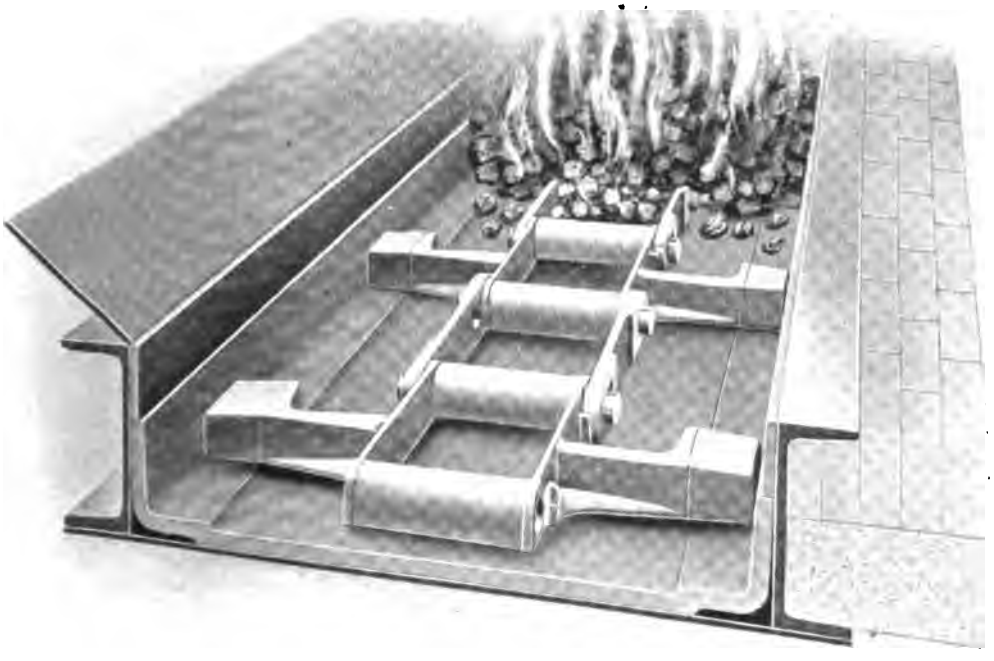


Fig. 177.—West's Hot-Coke Conveyor.

By this means the steam is kept in contact with the coke for a considerable time and ensures the coke being properly quenched. The quenching sprays are fixed to the top plate over the trough near the bottom of the slope, the surplus water draining out through a grid fixed to the trough side on the level portion near the bend. Guide rollers or wearing blocks are fitted at the bend to prevent the chains rising out of the trough, the angle of the incline deciding which shall be used. The return path for the chains usually consists of steel angles with cast-iron renewable wearing strips bolted on with countersunk headed bolts, supported either under or over the trough as is most convenient. The chain consists of best steel stamped block links (except

where the cross-bars come, these being of cast steel, cast solid with the cross-bars), alternating with double links, the block links being made specially high to take all the wear due to the rubbing on the wearing strips of the pan. The side links are connected in such a manner that the wear comes upon the full width of the portion passing through the hole in the block link and they are held together by rivets, which are made easy of removal while being perfectly secure and forming no part of the wearing surface. The two chains are held apart by 2½ inches by ½ inch flat cast-steel

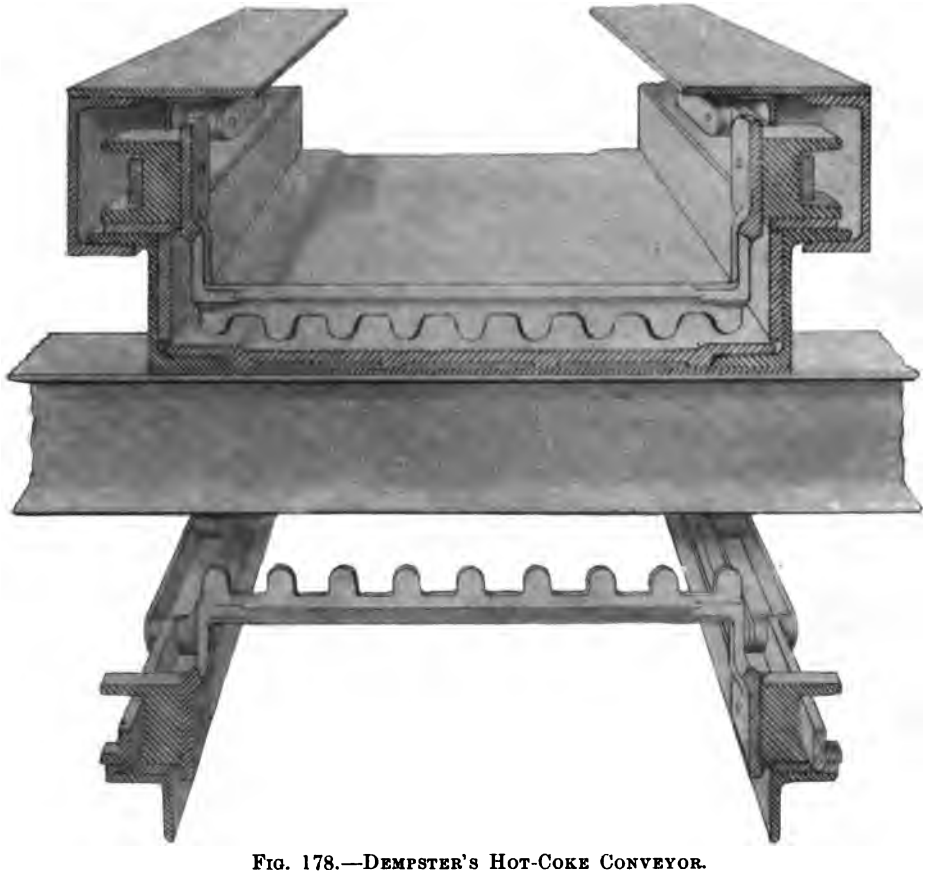


FIG. 178.—DEMPSTER'S HOT-COKE CONVEYOR.

bars cast solid with the block links at intervals of 2 feet 1½ inches, for the transmission of the coke along the conveyor. The conveyor is driven by cast-iron wheels fitted with renewable manganese steel sprockets, and at each bend passes round cast-iron flanged rollers. Suitable tension gear, as described on page 206, is provided for taking up any extension of the chain. A chain of the De Brouwer type will deal with from 50,000 to 60,000 tons of coke during its working life. The speed of travel of the conveyor is low, averaging about 40 feet per minute.

A somewhat similar type of hot-coke conveyor, but one in which a different type

of chain is employed, is shown in Fig. 177. Dempster's hot-coke conveyor is another familiar pattern. As will be seen from Fig. 178, it is of the rake type, and is so arranged that only the rakes are in contact with the coke, all the moving parts being on an elevated pathway and screened from the coke by means of baffle plates. Thus the chains and sliding shoes are clear of both coke and quenching water. The trough is formed of channels and Z-steel sides with steel bottom plate. The inside of the trough is provided with cast-iron liners and steel flat-bars on the Z-sections for the chain shoes to run on. As in the other types of conveyors the return can be arranged overhead if so desired. The chains are entirely formed of low carbon steel to prevent corrosion by acid fumes, etc., evolved by the coke during quenching. The rakes are of malleable iron, and the sliding shoes of chilled cast-iron.

Drake's Tray Conveyor

This hot-coke conveyor is unique in that it embraces the principle of carrying the coke and not dragging it. The general construction is shown in Fig. 179, from which it will be seen that the conveyor consists of corrugated trays mounted on wheels, and running in a cast-iron trough. There is in reality no wearing part with

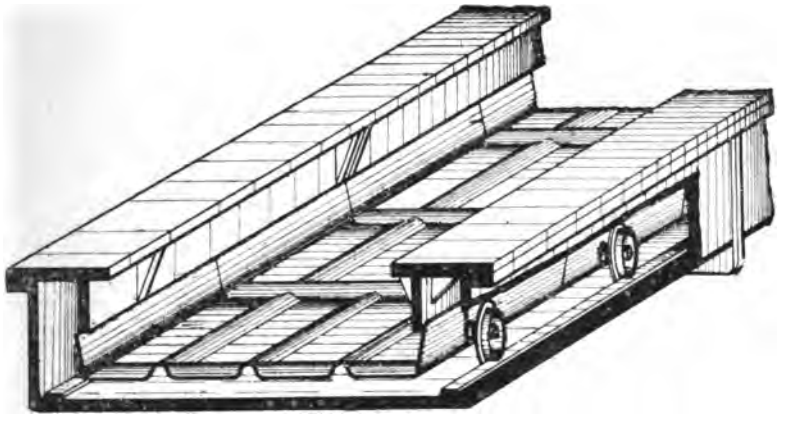


Fig. 179.—Drake's Tray Hot-Coke Conveyor.

the exception of the wheels, which revolve upon a fixed pin. The connexion between the trays is also by a pin, which acts as an axle when the trays are running round the drum, ready for the return. The trough is fitted with curtain plates which overlap the inside of the tray and which prevent the coke from getting over the side and into the path of the wheels.

Telpher Transporters

Transporters operating on the telpher principle are of comparatively recent introduction, having been first installed in this country by Siemens Brothers in

1903. There is no doubt that they are destined to play a prominent part in gasworks methods of the future. Their construction is too simple to need any detailed description here. The illustrations will best explain the chief features. The machine is provided with a cabin, in which the driver sits, and is driven by two electric motors, one for travelling and the other for hoisting. In the most common

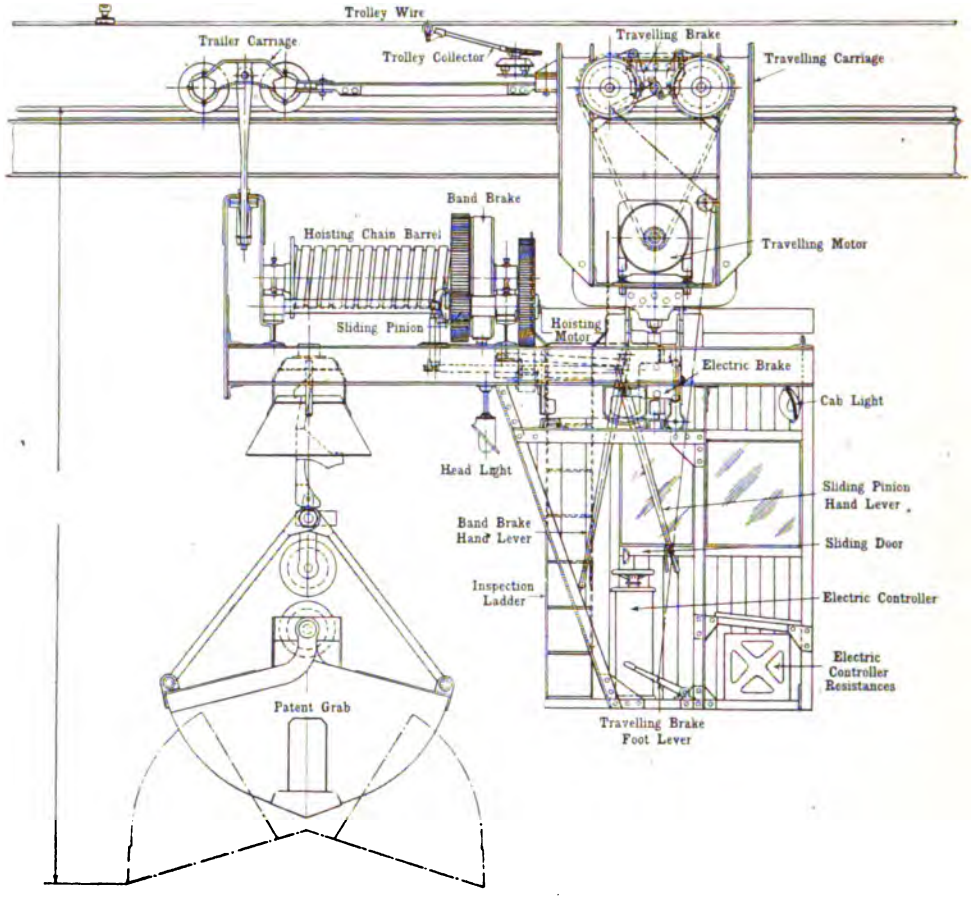


FIG. 180.—STANDARD TELPHER CARRIAGE (STRACHAN & HENSHAW'S TYPE).

types (Figs. 180 to 183) the travelling motor is of about 6 h.p., and the hoisting motor 12 h.p., for a machine of about 35 cwt. gross capacity. The power, of course, varies with the load to be dealt with and the speed required. The whole machine travels along a single track usually formed of a stiff joist with a rail section bolted to the upper flange. The two bogies on which the carriage is supported are pivoted to allow the machine to traverse curves of small radius,

and in some cases they are made to run on the bottom flange of the track girders instead of along a rail. Telphers are largely used for handling both coal and coke, and machines have been built to take loads up to 4 or 5 tons at a speed of 80 feet per minute. In such cases the lifting motor would be from 35 to 40 h.p. The system of dealing with hot coke direct from the retorts by means of lattice or bar skips attached to the hauling wire is probably

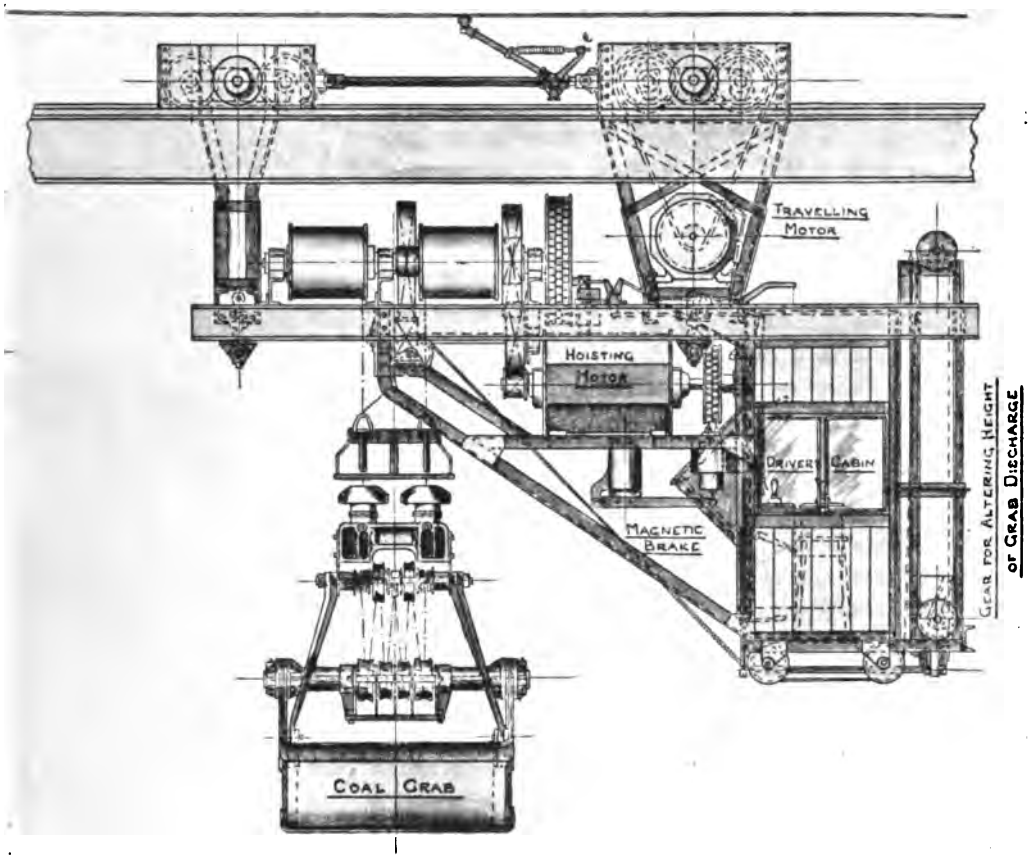


FIG. 181.—TELPHER AND TRACK.

one of the most ideal. The coke is discharged from the retort direct into the skip, which is hauled up, conveyed from the retort house, and lowered into a tank of water for quenching purposes. When quenching is complete the skip is raised from the tank, and the coke is automatically deposited at the required spot in the store yard. In the quenching of coke in this manner it is advantageous to permit as much of the cooling as possible to be performed by the escaping steam; hence

only the lower portions of the skip should be submerged. Wear and tear is considerably minimized with electric telphers, as the only portion of the apparatus in contact with the heated coke is the skip, which—with minor repairs—should last a number of years. The average machine handles gross loads of 2 tons with a hoisting speed of 80 to 100 feet per minute, according to the height of the hoist, whilst a travelling speed of from 400 to 750 feet per minute, according to the length of run, may be attained. This is ten to twenty times as great as the speed of the ordinary hot-coke conveyor.

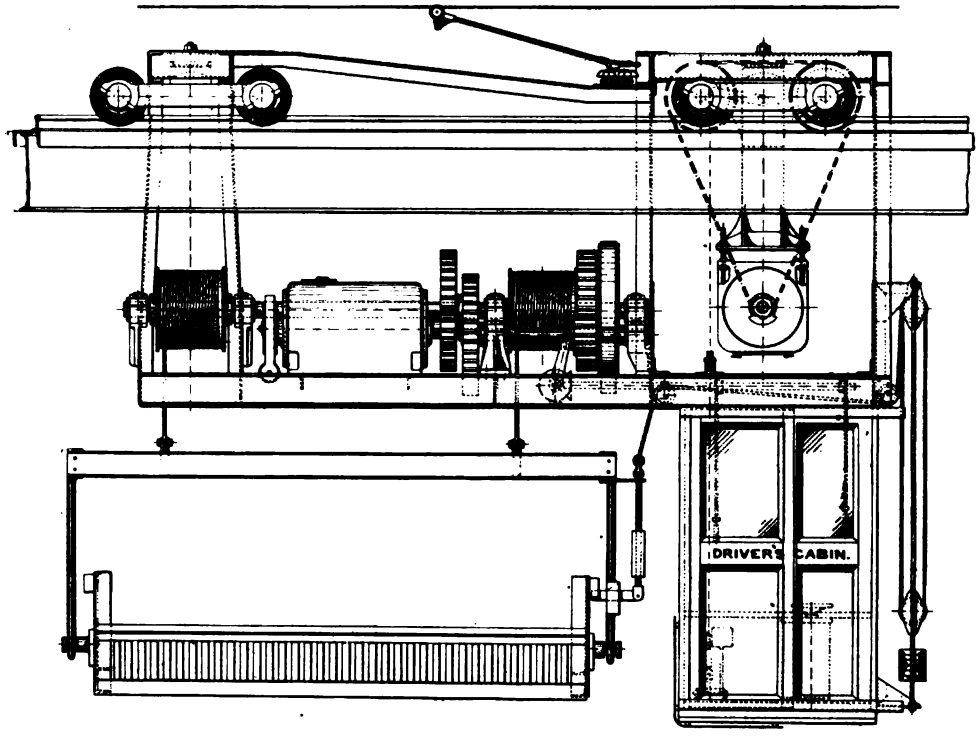


FIG. 182.—ELECTRIC TELPHER WITH COKE SKIP.

Probably the most satisfactory arrangement of trackwork is the method by which the telpher track is suspended from overhead steel lattice girders, these girders, having spans of from 60 to 100 feet, being supported at the ends by steel trestles. This arrangement gives the least possible number of obstructions in the yard, and there are fewer trestles to suffer from the corrosive action of the coke mass surrounding them. It is preferable in all cases where uprights are likely to be buried in coke to concrete these up.

The telpher collects its current from an overhead trolley wire attached to insu-

FIG. 183.—TELPHER SKIP BEING LOWERED INTO QUENCHING TANK.

lators above the track. A single wire is quite suitable when the engineer is able to utilize current which is generated at the works, as an earth return is then permissible, but in cases where current is taken from the town's mains two lines should be used, a positive and negative, so as to avoid the earth return. With regard to skips, which are the main renewable items, these cost about £30 each, for a capacity of 1 ton.

It may be pointed out that Continental practice favours the automatic telpher, that is a machine with which no man-handling is required. Such machines are controlled by electrical means from a fixed station. On the Continent the man-handled telpher is looked upon as somewhat old-fashioned and wasteful; but, on the other hand, the automatic plant introduces electrical complications which are, perhaps, best avoided in conditions such as obtain on gasworks. Very much more skilled attention is required, and when a breakdown occurs it is usually more difficult to deal with.

The Cost of Conveyors

In order to compare the relative costs of conveying machinery it is necessary to base figures on equivalent capacities for the different types in question. In general, costs are based on the outlay per foot run. Thus the total length of the installation has some influence on this item. The following table gives average figures prevailing in normal times, and should prove useful for purposes of comparison :—

(1) De Brouwer hot-coke type . . . . . £4 to £5 per foot run.

(Yard conveyors supported at a considerable height above the ground may entail an outlay of £6 per foot, which includes supports.)

(2) Travelling-tray hot-coke conveyor (Drake's type) . . . . £5 per foot run.

(3) Gravity-bucket conveyors—

		£ s. d.		£ s. d.	
(a)	Capacity 25 tons per hour	2 0 0	to	2 5 0	per foot run.
(b)	„ 30 „ „	2 5 0	„	2 10 0	„
(c)	„ 50 „ „	2 10 0	„	2 15 0	„
(d)	„ 80 „ „	3 0 0	„	3 10 0	„
(e)	„ 100 „ „	3 10 0	„	4 0 0	„

(The above prices, for an average length of 250 feet, include the chain, buckets, wheel curves, track rail, fillers, vertical guides, etc., but not the motor for driving.)

(4) Push-plate conveyors for coal—

		£ s. d.		£ s. d.	
(a)	Capacity 20 tons per hour	3 5 0	to	3 10 0	per foot run.
(b)	„ 25–30 „ „	3 10 0	„	3 15 0	„
(c)	„ 35–40 „ „	3 15 0	„	4 0 0	„
(d)	„ 50 „ „	4 0 0	„	4 5 0	„

(Conveyor complete, with exception of driving motor.)

FIG. 184.—TELPHER INSTALLATION SHOWING TRACK (STRACHAN AND HENSHAW'S TYPE).

	£ s. d.	£ s. d.	
(5) Tipping-tray conveyors for coal—			
(*a*) Capacity 50 tons per hour	6 10 0	to 7 0 0	per foot run.
(*b*) „ 80 „ „	7 0 0	„ 7 5 0	„
(*c*) „ 100 „ „	7 10 0	„ 8 0 0	„
(6) Bucket elevators—	£ s. d.	£ s. d.	
(*a*) Capacity 25–30 tons per hour	4 15 0	to 5 0 0	per foot run.
(*b*) „ 45 „ „		5 10 0	„
(*c*) „ 55 „ „	6 0 0	to 6 10 0	„
(7) Telphers—		£ s. d.	
Track and trolley wire.		3 10 0	per foot run.
Telpher and motors (each)			about £500.
Skips for coke (each), 1 ton capacity			„ £30.

THE CALCULATION OF HORSE-POWER

The power necessary to drive the various types of elevators and conveyors has in many cases been arrived at by practical experience and reference to the makers' records. It is, however, useful to be able to form an opinion as to the likely horse-power which will be required by any one installation, and the following simple but reliable methods will probably prove of some assistance to the designer.

First, in the case of conveyors such as the gravity-bucket and tipping-tray types, practical experience has shown that the tractive force is rather under 5 per cent. of the total weight of the moving parts and load. In addition to this 100 per cent. should be allowed for contingencies, such as neglect of lubrication and general inefficiencies. A gravity-bucket almost invariably performs two functions, first conveying horizontally, and secondly elevating the material. It therefore requires an operating power for a subdivision of these functions, namely :—

A. Driving the empty conveyor.

B. Carrying and elevating the material.

The calculation for operating power is therefore most easily made in three sections :—

(1) The power to operate the empty conveyor.

(2) The power to operate the load.

(3) The power to raise the load.

To formulate this—

Let L = length of conveyor chain in feet.

„ W = weight per foot run of conveyor in pounds.

„ l = length of conveyor loaded per foot.

„ T = capacity in tons per hour.

„ S = speed in feet per minute.

„ H = height to which material is to be elevated.

Then the total weight of conveyor and moving load (in pounds) is given by the formula—

$$LW + \frac{lT \times 2240}{S \times 60}$$

The result of the above formula gives the total weight in pounds of the moving parts, and 10 per cent. of this would be taken as the maximum pull (P) or driving effort on the chain of the conveyor. Resolving this into horse-power we get—

$\frac{PS}{33,000}$ = H.P. for chain and load *exclusive* of the power required to lift the material through a height.

The horse-power for lifting is represented by the formula—

$$\text{H.P.} = \frac{HW_1}{33,000}, \text{ where } W_1 = LW + \frac{lT \times 2240}{S \times 60} \text{ (as above).}$$

Adding the two results together gives the total power necessary for the driving motor. In a horizontal conveyor, of course, the second formula is eliminated. The calculation for tipping-tray conveyors can be carried out in the same manner.

As regards conveyors of the De Brouwer hot-coke pattern it is customary to allow about 1 horse-power for 40 feet run, and when the coke is taken up an incline the additional power entailed in raising the load must be added. The latter may be readily calculated as explained above. In all cases where the expression "foot run" has been used in this chapter, it refers to foot run of conveyor and not to the length of chain employed.

The horse-power required may also be readily arrived at by adopting a coefficient of friction in accordance with the conditions upon which the elevator is operated. The various cases would then be treated in the following manner:—

(*a*) Vertical elevator.

Let M = weight of material carried in pounds.
W = weight of moving parts in pounds.
K = coefficient of friction (*see* below).
S = speed per minute in feet.

$$\text{H.P.} = \frac{MS}{33,000} + \frac{KS\ (M + W)}{33,000}$$

(*b*) Inclined elevator.

Let O = angle of inclination with horizontal.

$$\text{H.P.} = \frac{MS \text{ Sin } O}{33,000} + \frac{KS\ (M + W) \text{ Cos } O}{33,000}$$

(*c*) Horizontal conveyor.

$$\text{H.P.} = \frac{KS\ (M + W)}{33,000}$$

So far as the value of K is concerned the following figures may be taken:—

Metal sliding on metal	0·15.
Ditto, well lubricated	0·07 to 0·08.
Wood sliding on wood	0·25.

The following table (Zimmer) gives a comparison between the relative power

absorbed by various types of elevators and conveyors. In each case the conveyor is assumed to be of 50 tons per hour capacity, and to have an effective length of 100 feet :—

	H.P.
Band conveyor for light materials	4·8.
„ „ „ coal	5·0.
Swinging conveyor	5·0 to 8·0.
Push-plate conveyor	12·8.
Worm conveyor	18·38.
Tubular worm conveyor	25·0.

CHAPTER IX

ELECTRICAL PLANT IN GASWORKS

THE growing use of electricity as a source of power for operating gasworks plant has rendered a knowledge of this form of energy of increasing importance. A close acquaintance with the details of technical electricity is by no means necessary, for the practical construction of the apparatus is in the hands of specialists. Every gas engineer should, however, aspire to a working knowledge of the subject and be in touch with the applications in practice of the more important theories. The importance of electricity has recently been emphasized by instances where gas concerns have, in addition, obtained powers for a public supply of current.

If electrically driven charging machinery is in use it is obviously economical in the majority of cases to operate other coal and coke-handling plant by the same means. As a general rule it may be said that the ideal conditions for all power consumers is the continuous use of a set of plant working at something approaching its normal maximum capacity. To this end, it can usually be arranged to work the coal-handling plant together with charging machinery for ten or twelve hours out of the twenty-four, and the charging machinery during the night only. In small works it is possible to make use of the coal-handling and charging machinery alternately with the same power installation, and in this way the necessary electrical plant is considerably reduced. If coke conveyors are also installed it can be arranged to use two out of the three pieces of plant at one time.

Electricity when generated by means of town gas is an extremely cheap form of power, particularly when it is used on gasworks, for in such cases the gas consumed should be reckoned on "cost into holder" figures. In comparing costs with those of steam-driven generating plant the expense entailed in the provision of boilers should be included. If, however, existing excess boiler power is available, then generation by steam has its attractions. Steam, moreover, may be produced by means of materials which may frequently be almost unsaleable. In general, however, preference should always be given to generation by gas, unless other methods present indisputable advantages.

DIRECT OR ALTERNATING CURRENT

In gasworks, where the current has to be transmitted only a very short distance, the most suitable system of supply—and that in common use—is the direct current. The advantages gained by the introduction of the multi-phase alternating system

(*i.e.* the transmission of high power through small cables and with little loss over a long distance) are, therefore, of no material account. Furthermore, the nature of the requirements of the various units to be driven does not call for the peculiarities of the alternating system. In fact, the starting torque of direct current is preferable with the majority of the motors employed. The alternating current demands more skilled attention, and there is greater liability to personal danger than with the direct system. The most common pressure in use is 220 volts.

Once the system of supply and the motive power for the generators has been decided upon the type and size of plant should be considered. For small and medium-sized installations the standard horizontal single cylinder gas engine is to be recommended, the electric-lighting type being specially built for this class of work. For very large sets the vertical high-speed engine with two or more cylinders is more effective. There are two methods of driving the dynamo :—

(*a*) By belting.

(*b*) Direct drive by means of a flexible coupling.

Method (*a*) accounts for a small waste of power, but carries the advantage that the speed of the generator may be greater than that of the engine. Accordingly, for the same power a smaller generator may be used. The direct-coupled machine will, however, last longer (owing to its slower running speed), is safer (owing to the absence of moving belts), and occupies less ground space. Taking all points into consideration, it will usually be found that a direct drive—in spite of the slight extra expense incurred—is preferable, and of more lasting economy. The engine employed should be fitted with a magneto ignition and self-starter, except in the case of very small units.

THE DYNAMO

A dynamo is a machine for converting mechanical into electrical energy. The mechanical energy supplied induces current in the armature windings, the current being collected by brushes and passing out for distribution to the switchboard. A small portion of the current is shunted through the field coils for magnetizing the field. The armature windings generate alternating current, and the commutator passes this out as a current of continuous flow (*i.e.* direct). Thus an alternating current dynamo, or "alternator," has no commutator. It is preferable when installing a gasworks dynamo to arrange for one having both series and shunt windings (compound), as this ensures a constant voltage for all variations of the load—this consideration being one of chief importance. The field regulating switch can be fixed either in series or parallel (or both) with the field coils. In practice, however, it is usually fixed on the shunt coils, as this permits of the adoption of a smaller rheostat, owing to the former not having to take the full load as do the series coils.

SIZE OF THE INSTALLATION

With regard to the size of the installation to be laid down it should be kept in mind, first, that it is necessary to arrange for more than a single plant, and, secondly, that it is not economical to work a set at much less than its normal capacity. In

large works the night load is much smaller than the day load, as little work, except that entirely inside the retort house, is carried out at night. In medium-sized works the difference in load may not be very great and, as already pointed out, in small works the load curve may be very nearly straight. In the last named case it is advantageous to instal duplicate plant, each set being capable of dealing with the maximum load. In some instances, where the difference between the day and night load is great, it may be preferable to have two plants of capacities equal to each period, with a stand-by equal to the lower capacity. Then, if the smaller unit breaks down there is a duplicate to take its place, and if the larger one requires repairs there will be two small sets for providing the power. It must be remembered, however, that two small sets such as these could not be run in parallel without special arrangements on the switchboard; otherwise the slightest difference in voltage would mean the slipping of current from one dynamo to the other. The best arrangement would be to depute one of the sets to driving the charging machinery, and the second could provide for the wants of the coal and coke-handling plant. With separate circuits and an arrangement of change-over switches either plant could be transferred to the other's work.

A Typical Example

Consider a works carbonizing about 200 tons of coal per diem, and having from 130 to 150 retorts. The larger number would represent the normal maximum work of a combined charger-discharger, or two-thirds the work of separate machines. For the purpose of the example it can be assumed that the maximum power required by the machine is 18 h.p. The necessary motors would, therefore, be on lines such as the following:—

	B.H.P.
Charging machinery	18
Breaker, say 20 tons per hour	11
Elevator, „ „ „	9
Coal conveyor, „ „	7
Coke conveyor	10
	55

Thus the maximum day load is 55 b.h.p. and the minimum night load 28 b.h.p. Motors of this type should run at an average efficiency of from 80 to 85 per cent. Assuming the lower figure, so as to allow for small losses between generators and motors, the following current would have to be supplied:—

$$55 \times \frac{100}{80} = 69 \text{ h.p.}$$

$$i.e., \ 69 \times 0{\cdot}746 = 51{\cdot}5 \text{ kilowatts.}$$

The latter, then, must be the power of the dynamo, *i.e.*, it must generate as a maximum 234 amperes at a pressure of 220 volts. In practice the next largest commercial size would be ordered, say 55 or 56 kw.

The efficiency of a dynamo rarely reaches more than 87 to 90 per cent., there-

fore the gas engine must supply sufficient power to allow for this loss. The power required at the coupling (assuming a dynamo efficiency of 88 per cent) is :—

$$\frac{56 \times 100}{88} = 63{\cdot}6 \text{ kw., or } = 63{,}600 \text{ watts.}$$

But 1 h.p. = 746 watts, therefore the required horse-power of the gas engine would be—

$$\frac{63{,}600}{746} = 85 \text{ b.h.p.}$$

The nearest convenient size would, therefore, be installed; and it is important to note on what basis the b.h.p. of the engine is given by the makers. Frequently the figures given in catalogues refer to the maximum power obtainable calculated on a town's gas having a calorific power of so much as 700 B.Th.U. Nominal or indicated horse-power need not be considered. With regard to duplication of the plant it must be remembered that although the day load amounts to 55 h.p., at times it will be very much less than this and the engine will not have a high load factor. In the event of the large plant being used for night work the load factor would be lower still (at times only about 20 per cent.), with a corresponding increase in gas consumption. During the night there may be an average required horse-power of 20 at the gas engine, and assuming a consumption of 22 to 24 cubic feet per horse-power-hour with the small plant, or, alternatively, 34 to 38 cubic feet per horse-power-hour with the large set, the difference between the consumption of the two sets is 13 cubic feet per horse-power-hour. It will be understood that this excess consumption of the larger engine is due to its working at about one-quarter load only. By using the larger engine on the night load (*i.e.* for about 10 hours at a stretch) the waste of gas per night would be :—

$$10 \times 13 \times 20 = 2{,}600 \text{ cubic feet;}$$

and if valued at 1*s.* 6*d.* per 1,000 cubic feet the monetary loss will amount to about 4*s.* per day, or £70 per annum. Thus in balancing up the merits of a single installation or two of half the capacity, it will be borne in mind that a saving of £70 per annum would be equivalent to the interest, wear and tear, and depreciation (in all about 10 per cent.) on a capital outlay of about £700. This sum would more than suffice to meet the extra cost of plant, switchboard, etc., for the duplicate plant. The amount of current necessary for electrically driven machines (chargers and dischargers) may be taken at 0·2 to 0·4 units per ton of coal handled.

THE MOTOR

The motor is the reverse of the dynamo, that is to say it transforms electrical into mechanical energy. The greater portion of the current supplied is absorbed by the armature windings, whilst a small portion is drawn off by the field windings, and the mechanical power obtained is derived from the energy of the current flowing through the armature in a magnetic field. Compound-wound motors are preferable for general use, for reasons similar to those which apply to the dynamo. For all

powers they maintain approximately equal speeds, which is not the case with the series motor, whose speed decreases as the load increases. The advantage of the latter type, however, is its heavy starting torque, which makes it valuable for quickly operated work such as tramways, cranes, etc. In cases where sudden release from the load is probable the series motor should not be employed, for, owing to the lack of governing power, "racing" would result, with a consequent tendency towards bursting. The compound-wound motor, whilst combining the commendable features of the shunt and series type, largely eliminates their defects, and is always to be recommended for general gasworks purposes. In order to effect economy in replacements it is preferable to keep to one type of motor and, if possible, to one make. It is not advisable to put down a larger motor than recommended by the makers, for loss in efficiency results and the average machine from a recognized maker will stand a temporary overload without ill effect. In the worst atmospheres and situations totally enclosed motors should be used. These have to be of somewhat larger size (and are consequently more expensive) than the "protected" types, in order to avoid the temperature rise which may result from lack of ventilation. The objection to the enclosed type, namely, difficulty of access, has recently been overcome by providing easily removable ends, thus exposing for observation the essential portions. For most purposes, however, the "protected" type is sufficient. It is smaller and cheaper than the enclosed type, and is fully capable of meeting all the demands made upon it when working in normal conditions of atmosphere.

SWITCHES AND ACCESSORIES

The switchboard fulfils a function of extreme importance, consequently every care should be taken to ensure that each detail is capable of the work demanded of it. The switches should be up to full capacity, and the workmanship should be of the best, down to the smallest details of bars, studs, etc. The board may either be built into the wall so as to give outside access, or may be placed well away from it so as to provide ample space for repairs. The fittings on the board will vary with the requirements and with different arrangements of units of power; but, generally speaking, each unit of plant has a separate panel, and the feeding units require a further panel. Each panel has a voltmeter, ammeter, main switch, and field regulating switch. The feeder panel will have main switches for each circuit of power equivalent to the respective motors. Tell-tale lamps or earth detectors should be fixed. These consist of two lamps in series; the pole at which earthing occurs is indicated by the extinguishing of one of the lamps. There is usually a small control board in the retort house with switches operating the various pieces of plant, whilst the motors must be provided with starters—preferably rheostats. Each should be fitted with a "no-volt" and overload release, which are combined safety devices giving full protection against all mishaps. The overload release cuts off the current when it reaches a pre-arranged amperage should there be an unforeseen stoppage or "jamming-up" of the coal plant, and in this way the windings of the motor are prevented from being burned out. Again, the starter may be left on by accident or inattention, and when the current is off the "no-volt" release brings it back to

"off," thus preventing burning out should the main switch be turned on in the absence of the operator. Ironclad switches should be made use of on the retort-house panel, the whole being boxed in and fitted with a glass panel for observation purposes.

With regard to cabling, electrical reference books give in tabulated form the grades and gauges of cables suitable for all powers. On the common forms of rating it is as well to work to that which gives the largest cable, as this item is a small one compared with the total outlay. Armoured cabling is preferable for most work, owing to its superior resistance to wet and damp, and its general flexibility. All cables should be laid in stoneware ducts; and it will be found good policy to leave a spare channel or two for use in case of possible extensions to plant.

CONSTRUCTIONAL POINTS

Many gasworks have their electrical plant installed in the subway on the charging side of the retort house, and in some cases in a partitioned portion of the coal store. Although economical, this is not a desirable practice to follow, owing to lack of space, indifferent ventilation, and the dusty atmosphere. A thin brick or reinforced concrete building entails but small expense, and permits of the house being designed to suit the lay-out of the plant, and not the reverse, as is so often the case. In the majority of existing subways it is impossible to put down a direct-driven plant.

All trenches for cables, gas and water pipes, etc., should be capable of easy inspection, and are preferably covered with some form of grid. If this is not done, a small inspection chamber should be built in at every point at which the direction of the cable or pipe is changed.

CHAPTER X

GAS-MAKING AND OTHER COALS

THAT coal is mineralized vegetation is a point on which all doubt has been removed. It is best defined as the product of the decay of vegetable matter under the prolonged influence of pressure, heat, and moisture. The classification of coals is based upon the geological period of their formation, the two main groups being known as "carboniferous" and "tertiary." It is the former which are generally distinguished by the name of "true" coals, and in this category are included steam coals and anthracites, cannel coals, and the mis-named bituminous types which, almost solely, are suitable for gas-making purposes. The tertiary coals, on the other hand, embrace those types of the nature of lignite or brown coal.

Scientific records appertaining to the gradual formation of coal from vegetable matter prove of little interest to the practical gas-maker, and the same almost may be said of the composition of coals as determined by ordinary laboratory methods. Nowadays, the gasworks value of a coal is gauged, not by its specific gravity or its unoxidized hydrogen content, but by its capability to conform with certain practical expectations. The constitution, as distinct from the composition, of coal is still more or less shrouded in mystery, although recent investigators, such as Wheeler and Lewes, have classified the main components in a manner which is of distinct service to those directly interested in carbonization. Composition as determined by ultimate analysis may almost be said to be of academic interest alone, and—according to one authority—is "as likely to afford an idea of the constitution of coal as the total weights of stone, metal, glass, and other materials forming Cologne Cathedral would convey an idea of its architecture and design."

The methods now in vogue for the examination of coal may be classified into two groups, namely, (*a*) Destructive methods, and (*b*) Non-destructive methods. Destructive methods have proved of certain usefulness in the past, but it is now generally realized that the constitution must be determined by such means as will not involve any radical change in the chemical constitution of any one of the component parts of the substance. The non-destructive methods which comply with this condition are, notably, microscopic examination of sections by transmitted light, the use of special solvents such as pyridine, aniline, and chloroform, and contact photography. The solvent processes, perhaps, can scarcely claim to come within the sphere of non-destructive methods, but their application has proceeded along with the scientific, as opposed to the directly chemical, means, and has resulted in the unearthing of much of the valuable information now at our disposal.

THE ORIGIN OF COAL

It is not proposed to follow out in detail the gradual formation of coal from the original vegetable matter. Sufficient is it to say that the respective changes are partly physical and structural, and partly chemical. The accompanying diagram (Fig. 185) enables the changes, so far as the salient properties and constituents of the coal are concerned, to be followed up. From this it will be noticed that the looseness of structure of the original matter gradually gives way to a more compact and homogeneous mass, whilst the volatile bodies are progressively displaced by constituents of a "fixed" nature. The moisture (*i.e.* the hygroscopic water), hydrogen, oxygen, and nitrogen of the cellulose all tend to be expelled, whereas the carbon remains, and increases in proportion as the process advances. The carbon, it must be understood, increases, not synthetically, but merely owing to the evolution of the remaining constituents; which fact is best illustrated by recalling that the volume of the final substance amounts to only one-tenth to one-sixteenth of the original vegetation from which it was formed.

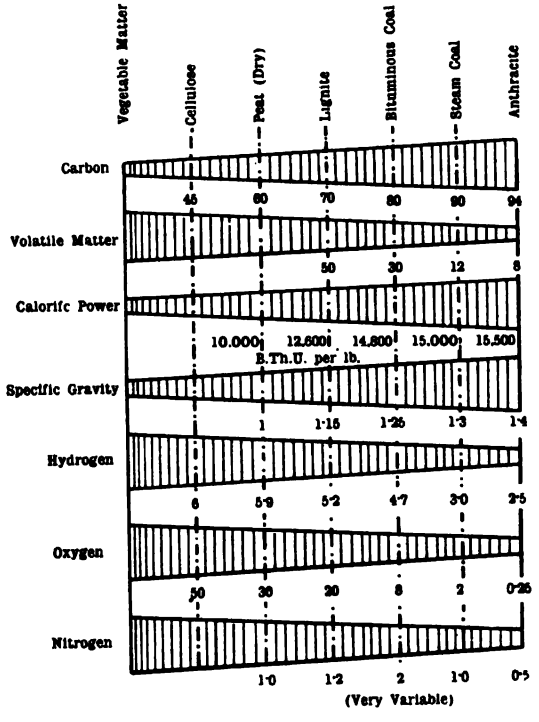


FIG. 185.—THE FORMATION OF COAL.

(The figures for the various properties and constituents vary considerably for the same types of coal. Those given above represent the average.)

Cellulose, one of the main constituents of vegetable tissues, may be considered as the basis from which the gradual evolution of coal can be conveniently followed. In its purer forms cellulose is best known to us as cotton-wool and paper. It has been shown that the carbonic acid exhaled by animal life and resulting from all forms of combustion is regenerated into oxygen by plant life coupled with the agency of the sun. Expressed chemically in its most simple form, the nature of this extremely involved action is somewhat as follows:—

$$6\ CO_2 + 5H_2O = C_6H_{10}O_5\ \text{(cellulose)} + 6O_2.$$

Experimental results in connexion with the artificial conversion of cellulose indicate that it undergoes changes on the following lines:—

$$4C_6H_{10}O_5 = C_{21}H_{18}O_2\ \text{(coal-like residue)} + 3CO_2 + 12H_2O.$$

Although, however, this may be true for artificial conversion, we know that in all natural conversion methane is produced; thus, considering pure cellulose, humus matter would be given by the decomposition, and the reaction would approach the following:—

$$6(C_6H_{10}O_5) = C_{11}H_{20}O_8 \text{ (humus)} + 8CO_2 + 7CH_4 + 6H_2O.$$

Bergius says that the differentiation of the various types of coal is not due to the time occupied in their formation, or to the prevailing temperature, but to marked increase in the pressure; and he supports his theory, and shows it to be in conformity with geological facts, by pointing out that anthracite has been formed where the earth's crust has become folded, thus squeezing the layers of carbonaceous matter to a terrific extent. Peat, lignite, bituminous coals, and anthracite form a series further and further removed from vegetation and wood in composition and character. The brown colouring of the lignite is a transition stage to the black of the coal, and whilst the vegetable structure disappears the specific gravity increases uniformly, until (as is now not generally disputed) the final stage of conversion is arrived at by the formation of graphite containing 100 per cent. of carbon. A point of importance to note is that a portion of the total carbon is in such a state of combination that it is capable of being volatilized, but this proportion decreases as the formation proceeds. It is for this reason that steam coals and anthracites are of no use to the gas engineer, owing to their indifferent capabilities as regards gas yields and coke. Steam coals are intermediate in composition between bituminous coals and anthracite, and should not be confused with the latter. In average bituminous coals, as used for gas-making, the volatile carbon amounts to from 15 to 20 per cent. of the total carbon, and is of extreme importance, in that it accounts on distillation for the most valuable constituents of the gas and tar.

THE CONSTITUTION OF COAL

As previously stated, the constitution of coal is not as yet wholly understood, and new light is continually being shed on the final mode of existence of the degradation products of the original vegetation. Investigators such as Lewes, however, have definitely established the presence of four fundamental bases in the substance, and these are classified as follows:—

(*a*) Carbon residuum.
(*b*) Humus bodies.
(*c*) Resin bodies.
(*d*) Hydrocarbons.

In general, the various types of coal owe their varying characteristics to the proportions in which these substances are present, and each of the constituents has its own distinguishable products of decomposition when subjected to distillation. For instance, the ability to form coke and to yield a high proportion of gaseous products depends upon whether the hydrocarbons and resin bodies are in excess (in which case the coal is of the gas-making type), or whether the carbon residuum or humus bodies are present in the greater proportion, when a non-caking coal of

an anthracite nature results. In fact, as the anthracite stage is approached the constituents are composed largely of the carbon residuum basis, the remainder consisting chiefly of resin compounds. Lewes says that for a coal to have the property of caking or "coking," the resin bodies and hydrocarbons have together to be present in the proportion of at least 50 per cent. In the ordinary type of gas coal the four constituents are present in approximately the following proportions:—

Carbon residuum	30 per cent.
Humus bodies	20 ,,
Resin bodies	25 ,,
Hydrocarbons	25 ,,

With an anthracite coal, on the other hand, the distribution would be more in accordance with the following:—

Carbon residuum	72 per cent.
Resin bodies	28 ,,

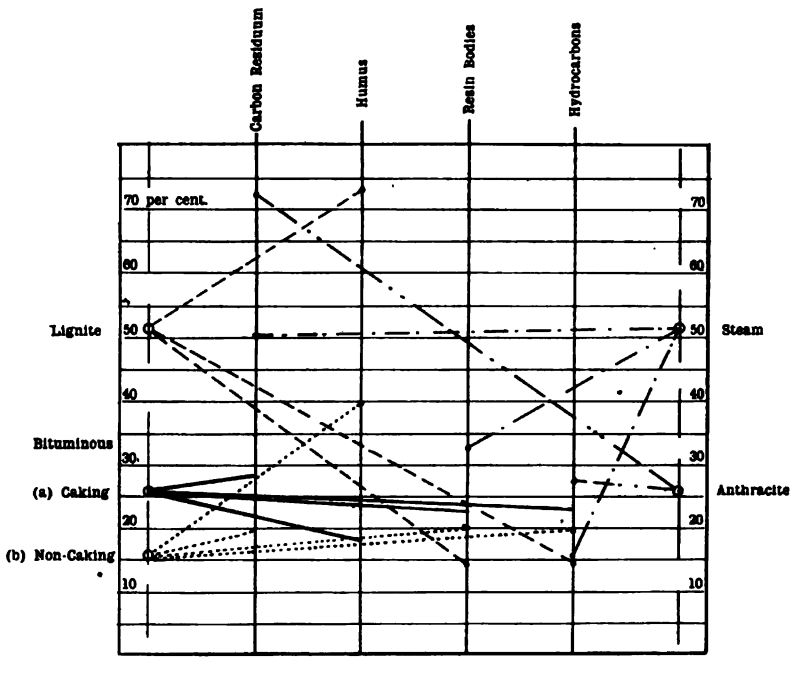


FIG. 186.—CHART SHOWING APPROXIMATE CONSTITUTION OF THE CONGLOMERATE OF VARIOUS TYPES OF COAL.

In this case it will be seen that the high calorific power of the anthracite coals is chiefly dependent upon the entire elimination of the low heating-power constituents. For instance, the humus bodies (which, on heating, account largely for water vapour, carbonic acid, and carbonic oxide, having a comparatively low calorific power) give way to resins and carbon. It is the humus which accounts largely for the low heating

value of the lignites. The approximate calorific powers of the four fundamental substances may be taken as follows :—

Resin bodies	16,400 B.Th.U. per lb.
Hydrocarbons	15,900 „ „
Carbon residuum	14,600 „ „
Humus bodies	13,300 „ „

From the above it will be seen that the maximum calorific power is yielded when the presence of the humus bodies can no longer be traced, as is the case with the anthracites and many of the steam coals.

Lewes points out that the composition of the humus and resin bodies is as follows :—

	Carbon.	Oxygen.	Hydrogen.
Humus	63	32	5
Resins	79	11	10

He shows that the whole of the oxygen present in the coal is due to these two bases. Hydrogen, in addition, is present in the hydrocarbon substance, but the unsaturated hydrocarbons in the gas are chiefly derived from the resinic compounds, whilst the hydrocarbon base is responsible for the paraffin group. In the past, authorities on carbonization have emphasized the importance of the " unoxidized hydrogen " content of the coal, and by deducting the quantity of combined hydrogen from the total have arrived at a figure for hydrogen which they consider of importance owing to the supposition that this is the only available hydrogen for the yield of free hydrogen and hydrocarbons in the gas. Thus a coal which on ultimate analysis shows 5 per cent. of hydrogen and 8·8 per cent. of oxygen would be rated on an " unoxidized hydrogen " content of $\left(5 - \frac{8{\cdot}8}{8}\right)$, $=3{\cdot}9$ per cent. It must be pointed out, however, that only a portion of the original oxygen in the coal combines to form water in this manner, a further material amount being found in combination in the condensible vapours forming the tar, and as oxides of carbon. Primarily, the proportion of oxygen gives a useful indication of the extent to which humus bodies are present in the coal, whilst the *direct* subtraction of the hydrogen percentage from the oxygen percentage enables an opinion to be formed as to calorific power. For instance, Constam and Kolbe have given the following figures :—

Coal.	Oxygen.	Hydrogen.	Difference.	Net calorific power.
	per cent.	per cent.		B.Th.U. per lb.
Nottingham, bright	10·20	5·30	4·90	13,912
Ditto hard	9·24	4·97	4·27	14,072
Durham I	5·66	5·48	0·18	15,392
Durham II	3·70	5·46	1·76	15,766

These figures clearly indicate that with coals of the bituminous type the calorific power is inversely proportional to the excess of oxygen over the hydrogen, and therefore bears a ratio to the quantity of humus bodies present. At the same time a know-

ledge of the percentage of oxygen is of decided value to the gas engineer, in that it conveys a useful idea as to the proportion of volatile matter. The latter is accounted for by both humus and resin constituents (in addition to the hydrocarbon bases), in both of which oxygen is present. Lewes has emphasized the importance of oxygen and has laid down the following axioms :—

(1) The higher the oxygen in the coal, the higher the volatile matter.

(2) The higher the oxygen, the lower the coke yield.

(3) The higher the oxygen the greater the amount of CO and CO_2.

(4) Oxygen above 10 per cent. or below 4 per cent. means inferior coke or indicates a non-coking coal.

As an illustration of the last statement the figures for the types of non-caking coals (about 13 per cent. of oxygen) and for anthracites (0·25 per cent.) may be recalled.

It must be realized that each of the fundamental constituents accounts for its own particular series of decomposition products. These, moreover, not only undergo variation according to the temperature of distillation employed, but are further affected by secondary reactions resulting from the influence of the heated walls of the vessel in which the coal is treated.

GAS-MAKING COALS

The quantity of coal now used for gas-making purposes in the United Kingdom amounts to about 16,000,000 tons per annum. Generally speaking, it may be said that the favourite coals of the gas engineer are those occurring in the Northumberland and Durham districts. Other fields from which large supplies are drawn are those of West Yorkshire, South Lancashire, Nottingham, and Derbyshire, also Staffordshire and Warwickshire. Owing to the decided variation in quality which occurs in coals mined in adjacent or even in the same seams it is difficult to distinguish with accuracy between the products of the different districts ; in fact, it is by no means uncommon to find both steam coal and gas-making types occurring in the seams of any one mine. The problem with which the gas engineer is chiefly confronted is that of balancing gas-making capabilities against expense of delivery. In the majority of cases it will be found most economical to take the coal nearest to the point of consumption, even though the quality is not all that might be desired.

In general, the typical analysis of a gasworks coal of good quality will approximate to the following, although as regards ash content it is by no means an uncommon occurrence to find the inert matter even in coals of good reputation mounting up to as much as 10 per cent.

Typical Gas-making Coal

Carbon	80 per cent.
Hydrogen	5·5 ,,
Oxygen	8·8 ,,
Nitrogen	1·5 ,,
Sulphur	0·8 ,,
Ash	3·4 ,,
Volatile matter	30 to 35 ,,
Calorific power	14,400 B.Th.U. per lb.

In the following table there are set forth the differences in ultimate analysis of typical coals from the various seams of the country; but, as already pointed out, it must be recognized that this standard of judgment is not to be relied upon. If used intelligently, however, the chemical composition of a coal will give some insight into its value for gas-making purposes. Particular attention should be given to the proportions of ash, oxygen, and sulphur. With regard to the last-named, although a certain amount may be chemically combined with the chief elements, and may accordingly form some portion of the conglomerate, the quantity so combined is extremely small, and forms but a fraction of that existing as iron pyrites (" brasses ") or sulphates.

TYPICAL BRITISH COALS

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.
Durham	81·1	5·37	7·01	1·56	1·12	3·84
Lancashire	77·91	5·40	9·32	1·31	1·45	4·61
Nottingham	77·36	5·66	10·22	1·34	1·65	3·77
Derbyshire	79·68	4·94	10·28	1·41	1·01	2·68
Scotland	78·53	5·63	9·22	1·00	1·11	4·51

So far as the Durham types are concerned, New Pelton and Holmside qualities are classified as " gas bests," whilst " gas specials " include Thornley, Wearmouth, and Londonderry. " Gas seconds " comprise types such as Pelton Main. Of the Derbyshire varieties the " deep softs " are those chiefly employed for gas production, the best-known qualities being Birley Silkstone and Mickley Thin. The West Yorkshire fields provide the chief sources of supply for the many large gasworks of that county, and of the typical gas coals the most notable seams are the celebrated Silkstone, also the Stanley Main, Beeston, and Middleton varieties. In addition, cannel seams are still being worked, but only to a comparatively small extent.

CANNEL COAL

Cannel or " candle " coal is unsuited to the present-day requirements of gasworks. It was somewhat extensively used in the days when statutory requirements as to illuminating power were more severe, and before the general introduction of carburetted water-gas as a source of enrichment. Although varying in constitution to some considerable extent, it is an extremely rich coal containing a high proportion of resinic bases. As regards its occurrence, the seams in some cases turn gradually, almost imperceptibly, into a bastard cannel, and finally merge into shale. Its characteristics resemble in many ways those of the Scottish gas-making coals. Cannel may be said to range in position between lignites and bituminous coals, and contains on an average as much as 45 per cent. of volatile matter. The chief objection to the use of cannel is the poor quality coke which it yields. The coke, owing to its powdery nature and high percentage of inert matter, is practically useless for fuel purposes. In some cases cannel coke will contain upwards of 60 per cent. of ash. The specific

gravity of cannel is rather higher than that of bituminous coal, and lies in the neighbourhood of 1·27. The ultimate analysis varies between the following limits :—

Carbon	64 to 85 per cent.
Hydrogen	5 „ 10 „
Oxygen	4·5 „ 15 „
Nitrogen	1 „ 2·5 „
Sulphur	0·3 „ 2·5 „
Ash	5 „ 20 „

As regards gas-making yields a high quality cannel is capable of giving, in exceptional cases, 14,000 cubic feet of gas, with an illuminating power of from 35 to 45 candles. The price of the coal, however, is prohibitive; and in normal times ranges around 35*s*. per ton (delivered London) for types such as the well-known Boghead, whilst the Yorkshire variety is valued at 28*s*., with the poor quality Derbyshire type at 18*s*. Cannel tar is of a distinctly paraffinoid nature.

SPACE OCCUPIED BY COALS, ETC.

For the purpose of estimating stocks of coal or coke it is necessary to have some idea of the space occupied per unit of weight by various solid substances. For the use of the gas engineer the following figures will be found suitable, but the physical condition of the material may account for some variation in either direction :—

1 Ton of—

Ordinary gas coal (unbroken) occupies	42 to 43 cubic feet.
„ „ (broken) „	40 „ „
Cannel coal (varies considerably) „	35 to 45 „ „
Anthracite „	35 „ 39 „ „
Coke (unbroken) „	85 „ 92 „ „
Breeze „	60 „ 65 „ „
Lime (1 yard = 12½ cwts.) „	42 „ „
Oxide of iron (Dutch) „	45 „ „
„ „ (Prepared) „	41 „ „
„ „ (Belgian) „	40 „ „
Sulphate of ammonia „	47 to 48 „ „

CONSIDERATIONS AFFECTING THE PURCHASE OF COAL

It is extremely difficult to lay down any hard and fast stipulations on which to base the purchase of coal intended for gas-making purposes. A final choice should not necessarily be influenced by a comparison of " makes " per ton and total residuals, but by a consideration of net financial standing after all charges have been balanced against receipts. It is for this reason that many concerns still adhere to the poorer classes of coal where the collieries producing these are near the gasworks, thus saving in freightage charges. High yields of gas per ton are undoubtedly alluring, but useful contrasts between the working results of different gasworks cannot be drawn on this basis. The only true gauge is the annual or half-yearly balance-sheet.

Most of the coals used in the gasworks of this country are of necessity rail-borne, and the following table gives the charges per ton from the chief colliery centres

to London. It is not possible to lay down any rate based on number of miles dividing works from colliery.

AVERAGE RAILWAY CHARGES FROM CHIEF COLLIERY GROUPS TO LONDON

Warwickshire (the nearest field to London with the exception of Kent)	5*s.* 1*d.* to 5*s.* 7*d.*
Leicestershire	5*s.* 7*d.* ,, 5*s.* 11*d.*
Nottingham	6*s.* ,, 6*s.* 6*d.*
South Derbyshire	6*s.* ,, 6*s.* 2*d.*
North Derbyshire	6*s.* 2*d.* ,, 6*s.* 8*d.*
Cannock Chase District	5*s.* 10*d.*
North Staffordshire	6*s.* 8*d.*
South Yorkshire	7*s.* 2*d.*
Lancashire	7*s.* 8*d.* to 7*s.* 10*d.*
South Wales	7*s.* 2*d.* ,, 7*s.* 9*d.*

These rates are to the main London stations, and in every case 1*s.* per ton extra is charged for wagon hire unless the consignee provides his own. South of the Thames or exceeding 150 miles from the colliery the rate is increased to 1*s.* 3*d.* The average cost of ship-borne coal in normal times (delivered alongside London from, say, Newcastle) is in the neighbourhood of 3*s.* per ton, if fair-sized colliers can be taken up to the point of delivery. If transference into barge is necessary, the cost will be increased to about 3*s.* 9*d.* per ton.

Coal for all the larger gasworks is purchased by contract, usually for a period of twelve months. In the ordinary way these contracts are entered into as dating from 1st July in each year, for a specified monthly quantity. In the majority of cases a fixed yearly price is settled, but occasionally a somewhat higher price for the six winter months has to be conceded. This margin may amount to 6*d.* or 1*s.* per ton. The various coal groups have by this time established a reputation, either good or indifferent, for the class of material they turn out; and as each district or [illegible] of seams has its own particular name, the name alone is often sufficient to con- [illegible] the purchaser of what he is buying. For all that, coals occurring in the same [illegible]lity vary considerably, and too much reliance must not be placed in a name. [illegible]ere are many methods of arriving at an approximate comparison between the [illegible]ilities of different coals for gas-making purposes, the chief being the following :—

(*a*) Proximate analysis. That is to determine, chiefly, the volatile content. This gives some gauge of the gas-yielding and coking properties of the coal. The test is best carried out by Dr. Lessing's method, in which electrical heating is employed.

(*b*) The calculation of pounds of sperm per ton, or the pounds of sperm which can be purchased for a shilling. This is a time-honoured method which has proved of some value in the past, but which is scarcely in conformity with modern applications of gas. To obtain the value of a coal in pounds of sperm per ton the make of gas per ton is divided by 5 (which is the cubic feet of gas consumed by the standard test burner per hour); the result is then multiplied by the illuminating power and by 120 (120 being the number of grains consumed per hour by the standard sperm

candle). Finally, it is necessary to divide by 7,000, which is the number of grains in 1 lb. Put briefly :—

Pounds of sperm per ton = make × illuminating power × ·003428.

(*c*) Calculation at current prices of total yields of gas, coke, etc., obtained from a ton of the coal. The figure obtained is then balanced against the cost of the coal, and comparison between various coals is made on these lines. This method cannot be applied with accuracy, and is not to be recommended.

(*d*) The use of a coal-testing plant. On the larger works it is still customary to submit small samples taken from fresh consignments of coal to a laboratory experimental plant. The total gas evolved, in addition to the main by-products, is then carefully collected and measured. The usual procedure is to take $\frac{1}{1000}$th part of a ton of coal (2·24 lb.), which is carbonized in a small cast-iron ⊂-shaped retort, 5 inches × 4 inches × 3 feet in length.

The coal-testing plant of the Birmingham Corporation gasworks is probably the most elaborately equipped of those now in use. It is on an exceedingly large scale, and in reality forms a complete gasworks in itself. Various types of retort settings are in use, including regenerative horizontal beds, and both intermittent and continuous vertical systems. The horizontal test bench is capable of dealing with 31 tons of coal per diem, and consists of four beds of full-sized through retorts. The intermittent vertical installation has a capacity of 14 tons a day, and the continuous bench is capable of dealing with 20 tons per diem. Elaborate apparatus is installed for the purpose of arriving at an accurate knowledge of the capabilities of the various coals tested, and their behaviour under different systems of carbonization.

(*e*) Comparison by "gas multiple." This is one of the most recent methods, and can be looked upon as affording the most satisfactory means of comparing the gas-yielding proclivities of various coals. The yield per ton is obtained by careful experiments in the test plant, and the illuminating power of the gas evolved is noted. The "make" of gas is then multiplied by the candle power, and the result gives the "gas multiple."

For example, two coals (*a*) and (*b*) might be tested with the following results :—

(*a*) 12,000 cubic feet of gas per ton. Candle power, 15.

(*b*) 13,000 ,, ,, ,, ,, ,, 14.

Then for (*a*) the gas multiple is 180,000, and for (*b*) it is 162,000. Coal (*a*) would then be adjudged the most desirable from the point of view of gas yield. In some cases it is customary to multiply the gas "make" by the calorific power of the gas, in lieu of the candle power.

Whatever method of testing is undertaken, the importance of the by-products, tar and liquor, must not be overlooked, for an enhanced yield of these is frequently more profitable than a slightly increased gas "make" obtained from some other coal or by varying the method of carbonizing the same coal. At the same time it must be borne in mind that a low gas yield means more coal to make the necessary quantity of gas, consequently higher charges for handling and transport.

CALORIFIC POWER RECOVERED

Suggestions have recently been made that calorific power should be made a basis on which to adjust the value of coal. Thus a certain price per ton would be charged for a definite calorific power, and a *pro rata* reduction made when the heating value was below the standard. For those who employ coal as a fuel the system has many advantages. The gas engineer, however, is concerned not so much with the number of heat units in his original coal, but with the number which will be recoverable on distillation, and—more particularly—in what form they will be recovered. The latter consideration is rarely accorded the share of attention it merits, but a simple illustration is sufficient to indicate its importance. Of the original heat units in a ton of coal about 95 per cent. are recovered in useful form in (*a*) the gas, (*b*) the coke, (*c*) the tar. First, it must be considered in which of these three forms the B.Th.U. are the most profitable. Now, 10,000 B.Th.U. are contained in 18 cubic feet of gas, and in this form yield approximately $\frac{3}{4}d$. On the other hand, 10,000 B.Th.U. are contained in about $\frac{1}{16}$th lb. of coke, and in this form yield $\frac{3}{40}d$. It is clear, then, that in the form of gas the recovered heat units are several times more valuable than is the case when they are recovered in the coke, even when the cost of gas into holder is considered. The original calorific power of the coal should, therefore, be realized in the gas as far as possible, this being the most profitable outlet for the heat units. According to investigation, coke accounts for about 60 to 65 per cent. of the original calorific power of the coal, tar for from 6 to 8 per cent., and the gas for 25 to 35 per cent., whilst a loss approaching 5 per cent. is generally found. The loss will be partly accounted for by retort carbon, and may be partly the outcome of the supposed thermal nature of the carbonization of coal (*see* page 95).

COAL WASHING

All coals as won from the pit contain varying proportions of inert matter or otherwise undesirable impurities. Chief amongst these are siliceous and calcareous matter, also shale and pyrites. In former times a considerable quantity of the coal hewn was regarded as worthless and often left below ground, and were it not for the methods of washing employed many of the inferior seams would be unprofitable to work. With the perfecting of washing apparatus even abandoned measures have been reopened, and material containing so much as 20 per cent. of impurities is rendered of marketable value. In such cases it is difficult to reduce the undesirable matter below about 6 per cent., but the more general practice is to treat those coals containing originally about 8 per cent. of impurities, these being ultimately reduced to 2 per cent. or even under. The principle of coal washing is based upon the difference in the specific gravity of coal and of the impurities intermixed with it. Water is the separating agent employed, and if the mixture is allowed to fall through a tank the heavier particles will sink more quickly than the lighter ones. The relative specific gravities of the various substances are approximately as follows :—

Coal, 1·25.
Shale, 2·5.
Pyrites, 3·5 to 5.

Coal washers now in use consist of two distinct types, namely :—

(*a*) Running water, down some form of inclined trough.

(*b*) Mechanically agitated water.

The first type was introduced in the early days of the process, and is fast giving way to the more scientific mechanical plants. Of the latter plants there are several varieties, such as the Blackett, the Elliott, the Robinson, and the Baum washers. In nearly all types it is customary to screen the coal before washing, and then to treat each grade as desired for the elimination of impurities. The Baum washer, however, is operated on the principle of "first wash, then classify," and is shown in Fig. 187. Any coal below 3½-inch mesh is washed without previous screening in one washer box, the specifically heavier products going to the bottom and the lighter products (*i.e.* the coal) going away with the water. The Baum washer is capable of dealing with any quantity of coal up to 150 tons per hour, and the application of the water is effected by air at a pressure of about 2 lb. per square inch. The air valve is provided with a sleeve piston which is raised and lowered by an eccentric. When the valve is in the lower position air passes direct from the blower and exerts its full pressure on the surface of the water. When the valve is in the upper position the air supply is cut off from the washer box, which is simultaneously opened to the atmosphere. In this way, alternate depression and rebound of the water take place. The coal to be washed, lying on the grid *R*, is thus subjected to the pulsations of the water, and the dirt falls to the bottom, whence it is removed by the elevator, *Q*. The worm conveyor, *S*, collects towards the elevator any dirt deposited further along the washer box. The coal, along with the middles and light dirt, overflows into a second section of the washer box, where it undergoes further treatment, the good products overflowing at *N* to be dealt with according to requirements. The washing water enters at *T*, and passes with the washed coal over the outlet *N*. It is afterwards clarified before being returned to the box.

Coal after washing is usually allowed to drain in bunkers and to dry in the air. The cost of washing by modern methods is trivial, amounting to from 2*d.* to 4*d.* per ton, according to the capacity of the plant, whilst the value of the coal may be enhanced by the process by anything from 6*d.* to 1*s.* per ton. As regards the percentage of moisture in washed coal, this depends upon the size of the coal, weather conditions, etc., but it may be as much as 10 per cent. over that in the normal sample.

THE STORAGE, SPONTANEOUS COMBUSTION, AND DETERIORATION OF COAL.[1]

The problem of the spontaneous combustion of coal is one which the gas engineer is continually called upon to face, owing to the fact that the bituminous coals used on gasworks suffer most in this respect. Cannel coals are less affected, and steam coals and anthracite are least liable of any. Originally, there was a general opinion among gas engineers that spontaneous ignition was due to the oxidation of the "brasses" or pyrites in the coal, and that the action was greatly accelerated by damp and moisture, the pyrites being oxidized by the oxygen contained in the water.

[1] See the author's article in the *Journal of Gas Lighting*, vol. cxix. page 616.

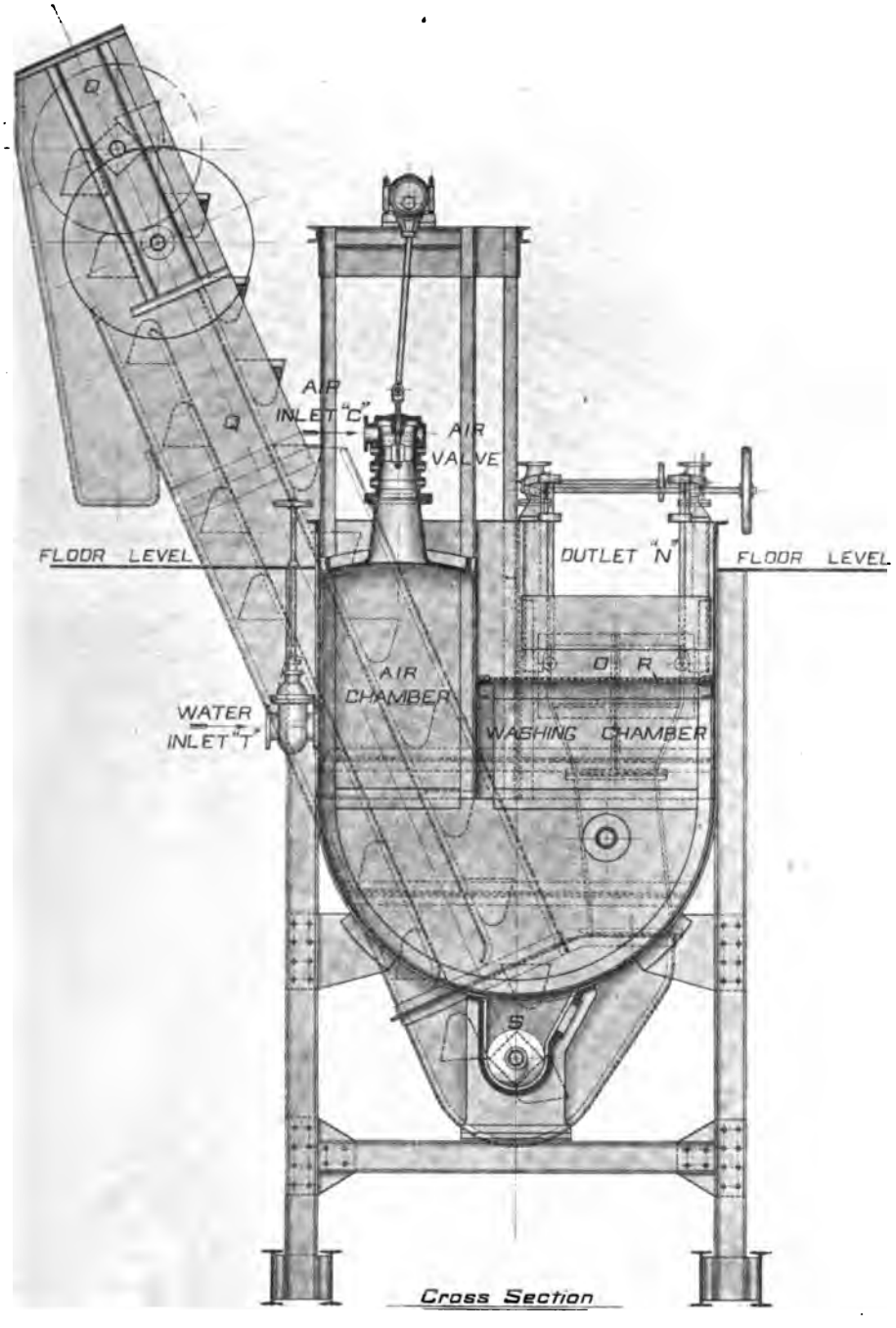


FIG. 187.—THE BAUM COAL WASHER.

This idea probably originated in the fact that if a quantity of pyrites is picked from the coal, made into a heap, and then exposed to air and moisture, the heat of the pile rapidly rises, owing to the oxidization of the sulphur due to the action of the air and moisture. In many cases a temperature will be reached at which combustion in air begins, and the mass will then burst into flame. In contradiction of this theory, however, it must be pointed out that while some coals containing a very high percentage of pyrites are quite safe, those containing a small proportion often give great trouble when stacked.

There seems to be little doubt, then, that spontaneous combustion is the outcome of a combination of several causes, and that while pyrites itself is not alone responsible, it plays some subsidiary part in assisting the action. Factors such as the size, dampness, proportion of volatile matter, and general composition, all play their part in bringing about a rise in temperature. It is, however, interesting to note that conclusions arrived at by the United States Bureau of Mines were that moisture plays no part in promoting spontaneous heating, and that high volatile matter does not of itself increase the liability to fire.

It is common knowledge that coal as soon as it leaves the seam has a great avidity for oxygen, and, remarkable as it may seem, the greater the proportion of oxygen in combination with the coal the greater appears to be its proclivities for absorbing an additional quantity from the air. Lewes pointed out that the "resin bodies are the compounds present in the coal most likely to possess this property. It is the chemical actions so caused which lead to slow combustion, and, when accelerated by any rise in the surrounding temperature, this is capable of generating sufficient heat to lead to the spontaneous ignition of masses of broken coal large enough to prevent the escape of heat as it is developed." Many bituminous coals will absorb more than three times their volume of oxygen; but after a time they get coated with an oxidized surface, and their absorptive properties become less vigorous until new surfaces are exposed by the breakage of lumps, etc. It is probable, then, that the spontaneous heating in coal heaps is due to the rise of temperature occasioned by the oxidation of part of the carbon together with the sulphur in the coal; and in cases where actual firing takes place, it may be assumed that the heat generated in the stack is greater than that dispersed by radiation. Thus the temperature rises till the ignition point is reached. The greater liability of some coals to fire is due, therefore, not to the sulphur they contain, but to their proclivities for absorbing oxygen; and the greater the quantity of oxygen absorbed, the greater will be the tendency to fire. The heating effect, too, is probably cumulative; for a rise in temperature increases the capacity of the coal for taking up oxygen.

Means of Prevention

On the question of the actual cause of spontaneous ignition there is a certain amount of uniformity among the opinions expressed, but the same cannot be said with regard to the best means of preventing its occurrence. Many divergent views have been brought forward. In the reports of the German Gas Association a Mariendorf engineer is found strongly advocating ventilation as a means of preventing ignition,

but his views are contradicted by others, who infer that ventilation actually causes fire. Again, it is noticed that the New South Wales Commission on the Spontaneous Combustion of Coal in Bulk recommended a "free use of the hose pipe," whereas another authority points out that the use of water is likely to be followed by serious results and possible explosion, especially in confined stores. Primarily, then, it is necessary to find out the conditions actually favourable to combustion. In the first place, there seems little doubt that there is far greater liability in hot weather than in cold. With regard to the question of ventilation, many opinions have been expressed; and some few years ago it was quite a regular practice to resort to such expedients as perforated iron pipes, wickerwork baskets without bottoms, also elaborate ventilating shafts of brick and wood, so as to ensure the passage of a good strong current of air through the heap. Great caution, however, is necessary, for it must be borne in mind that when once a fire has been started it will not continue to burn unless the supply of oxygen is maintained; and very often the ventilating shafts, by the formation of a draught, supply the necessary oxygen for sustaining and augmenting the fire. Unless ventilation is thorough, therefore, it is liable to cause great mischief. Perhaps, taking everything into consideration, it may be wiser to adopt surface ventilation only.

Owing to the greater tendency of some coals to fire, it is as well to keep the various classes in distinct heaps as far as possible. Experience has shown that it is inadvisable to stack all the large coal in one heap; for probably, owing to disintegration, a "dust-pocket" will be formed somewhere towards the bottom. The spaces between the lumps afford excellent opportunities for the creation of a draught, and, consequently, a steady supply of air to the pocket. In such a case we get conditions similar to those occurring with insufficient artificial ventilation. The heap should be piled so that lump and fine are distributed as evenly as possible. A point which usually escapes observation is the tendency of the large lumps (when tipping on the apex of a heap) to run to the outside, leaving the centre of the heap composed of slack. This is undesirable, and the coal should be spread out as the heap is built up. English coal spread out in this way was stacked at Berlin to a height of 46 feet for more than twelve months, and no trouble was experienced with it. The depth of the heap is another point which has received a good deal of attention. According to information available, it appears that there is some relation between the liability to spontaneous combustion and the height and volume of the heap in which it occurs. There also appears to be a "critical height" above which it is inadvisable to go, and for ordinary coals this ranges between 15 and 20 feet. Excessively high heaps should, of course, be avoided as far as possible, for pulverization is sure to take place towards the bottom.

Dealing with a Burning Heap

The undue heating of a coal heap is usually accompanied by "steaming" and an offensive smell, due to the escaping hydrocarbon vapours. When these are noticed, the usual procedure is to turn the hose on to the apparent seat of the trouble and drown out the fire. When a fire does occur, however, it is necessary to avoid

the use of water until the area actually affected has been located. The coal round about this area should then be dug out, and the smallest possible quantity of water made use of. By far the best practice is to get the affected coal away to the retort house and carbonize it as soon as possible.

A coal heap should be kept continually under observation. The most usual means of recording the temperature is that of inserting 1½ to 2-inch pipes, one end being knocked down to a point. A thermometer—attached to a cord—can then be lowered into the pipes and the temperature noted. As the drop in temperature while the thermometer is being withdrawn is likely to be somewhat considerable, a more accurate reading will be obtained if a maximum thermometer is used. When greater accuracy still is required, it is necessary to use a low-temperature pyrometer with electrical connexions. A great deal of trouble will be saved if the temperature pipes are suspended in position before the heap is made, for the task of forcing them down into an existing heap is certainly tedious. An idea from America is that of a coal auger, the head of which contains a small maximum thermometer. It is claimed that the point of the auger can be driven 20 feet in from three to five minutes, and about ten minutes is required for the thermometer to attain the temperature of the surrounding coal. Temperatures taken in this manner have been found to be 40° higher than by the pipe method—the difference being ascribed to the circulation of air in the pipe. When the temperature rises above 90° Fahr., the upper layers of coal at least should be removed. Disturbance of the heap by driving in rods, etc., to the seat of the fire should be avoided, for this merely has the effect of inducing air currents, and hence provides an additional supply of oxygen. When a fire actually breaks out, some prefer to use sand instead of water. While water cools the material and reduces the temperature below ignition point, sand smothers the fire and cuts off the supply of oxygen. Sand certainly recommends itself for use in cases in which the action of water is known to have a deleterious effect upon the surrounding coal. If the fire were large, however, it would probably afford but little check.

Vertical Retorts and Wet Coal

That damp coal has an undesirable effect when carbonized in ordinary retorts is indisputable. In works in which there are chamber-ovens or vertical retorts, the moisture matters but little. Accordingly, the dry coal could be reserved for the horizontal house, while the wet coal could be disposed of in the verticals. For some unexplained reason, certain coals prove themselves particularly liable to spontaneous combustion when under a covering of snow. Occasionally fires have been caused by hot pipes which run through the heap or under the ground upon which the coal is stacked. Thus it appears that a very small source of external heat is sufficient to start the action, especially if the heat is local and applied towards the centre of the mass. Another point is that of the local application of water. While a shower of rain seems to have little effect, a stream of water confined to one small area will probably cause a rise in temperature. This is best illustrated by the case of the covered coal store with a leaky roof, and the fact that fires frequently occur directly

under the leak. Leaky water-pipes in the vicinity of the heap very often lead to trouble.

Finally, for the prevention of heating, and for the treatment of fires, the author suggests the following points:—

1. Stock different types of coal in separate heaps.
2. Surface ventilation only.
3. Mix lumps and fine together. Small heaps are less dangerous than large ones.
4. Do not pile to a greater height than 20 feet.
5. Avoid external sources of heat, such as hot pipes.
6. Attend to leaky water-pipes or gutters in the vicinity of the heap.
7. When temperature rises to 90° Fahr., remove top layers and carefully watch.
8. Do not disturb the fire by pushing in bars, etc., from the side of the heap.
9. Apply water to the seat of the trouble only, particularly if fire occurs in confined stores.
10. Remove and carbonize the affected coal as soon as possible.

Deterioration

The deterioration of coal due to storage is another vexed question. Though all are agreed that some loss does take place, the estimates as to the amount vary considerably. The question has probably received far more attention in Germany than in this country. Herr Prenger, engineer of Cologne gasworks, has found that the decrease in gas-making value of English coal is from 3 to 15 per cent., or an average of 7 per cent., when stored in the open, and from 0 to 10 per cent., or an average of 4 per cent., when stored under cover. Some authorities state that practically no deterioration occurs. No doubt a great deal depends on the class of coal in question. The coal miners' strike of 1912 afforded an opportunity of gaining some experience on the subject, and, judging by working results, those coals which had been lying in stock for some years undoubtedly yielded less gas, less ammonia, and a rather inferior coke—the coke giving a greater proportion of breeze. The loss in calorific value appears to be quite slight, although the heating value of the coke is reduced in some cases. This usually makes itself felt in the percentage of coke used as fuel. The results of some experiments carried out on the coal-testing plant at the Saltley gasworks of the Birmingham Corporation by Dr. Davidson showed that the gas multiples for coals which had been stocked for periods of six months to two years were in every case lower. No definite loss per annum is fixed by the tests, but it would appear to be no more than 2 per cent. The experiments showed that while the gas value decreased the liquor increased very appreciably; but the coke was markedly inferior. The following figures are those given by a well-known English gas coal which was tested after the intervals stated:—

	Moisture.	Make per ton. Cubic feet.
On arrival	2·71	11,818
After 3 months	5·22	10,708
„ 5 „	5·64	9,780
„ 6 „	7·58	9,630

THE STORAGE OF COAL

The ideal state of affairs on a gasworks would, of course, be to take in just as much coal as is required for present requirements, so as to avoid any necessity for keeping a stock in hand. Owing, however, to the fluctuating output of gasworks, and to the fact that collieries turn out an amount which is fairly constant all the year round, these conditions are impossible. Moreover, in some cases a reduction in price may be obtained for coal delivered during the summer months; and many gas companies are eager to seize upon this opportunity. In respect to coal deliveries, the United Kingdom is more fortunate than many other countries. In Germany, for instance, some works are obliged to take the whole of their coal during the summer season, owing to waterways being closed by frost throughout the greater part of the winter. In the same country, too, stored coal is liable to deteriorate to a far greater extent, owing to the wider variations of temperature and fluctuations of weather conditions.

At the present day far more coal is stacked out in the open than in elaborate stores, such as were erected as part of the retort house on nearly all works in years gone by. There are still, however, many believers in the indoor method; and there is no doubt that coals deteriorate to a much less extent when sheltered from the weather. The opinion is expressed by some engineers that coals are just as likely to heat up under cover, and when they do so they are far more difficult to get at. Under any circumstances, care should be taken to see that the store is not situated too near to the heat of the retort bench. It is with stores of the closed type that particular care is necessary with regard to the use of water. When coal is stacked in a bin and takes fire, the application of water to the red-hot carbon will in all probability be followed by the formation of water gas. This gas, in addition to being a source of danger to the men, owing to its poisonous nature, may mix with a sufficient quantity of air to form an explosive mixture, which might conceivably result in the destruction of the bin. When coal is stored in covered bins some arrangement should be provided by means of which the affected layers, which are frequently at the base of the heap, may be summarily removed. For this reason the more recent practice of constructing a small tunnel from end to end of the store and below floor level is to be strongly advised. The tunnel is made sufficiently large to take a conveyor, and by means of pouches fitted with sliding doors placed at frequent intervals the coal in the affected area can be quickly removed and carbonized. An arrangement of this nature is seen in Fig. 188.

The Storage of Coal under Water

Owing to the tendency of stored coal to fire the practice of submerging the heaps in water has recently been adopted. In such cases special reservoirs, usually constructed of reinforced concrete, are required. The method has, so far, been confined almost solely to America and the Continent. When submerged, the coal is protected more adequately than if it were housed; and no matter what the weather conditions, the variation in temperature of the mass will be comparatively small.

It is now generally recognized that the gases occluded in the pores of the coal—more particularly oxygen—are indirectly the cause of heating and deterioration. The escape of the oxygen should therefore be arrested as far as possible. By immersing coal and keeping it continually sealed this condition is fulfilled, the gases being more or less confined, whilst little or no oxidation takes place. Breaking up of lumps and pulverization are also considerably reduced, because the water forms a cushion between the various pieces, thus lessening the effect of the movement of the lumps.

FIG. 188.—COAL STORE TUNNEL SHOWING CONVEYOR AND POUCHES.

one on another. The better physical condition of the coal is, however, probably due, in part, to the absence of heat, which in itself is to a great extent the cause of the opening out and disintegration of the larger pieces. There is no limiting depth for the heaps of coal when immersed, and accordingly a considerable saving of space can be effected; in fact, by adopting the wet method the capacity per unit of ground area could be easily doubled. The most undesirable factor in connexion with the system is that of expense. One of the largest reservoirs for storing coal in this way is that on the banks of the Oder, at Stettin, where 20,000 tons may be submerged.

Another series of tanks for storing coal, at Omaha, U.S.A., are 22 feet in depth, with the side walls carried on piles. Piles are also driven under the whole of the floor area at a pitch of 5 feet, and are capped with square slabs of concrete on which the floor rests. The side walls of concrete are about 2 feet thick at the top and 4 feet 6 inches at the bottom, whilst the concrete floor is protected from the bite of the coal "grab" by means of embedded rails.

As an instance of the immense stocks of coal held in reserve on gasworks it may be mentioned that the bunkers at the Tegel works at Berlin are over half a mile in length and are capable of containing nearly a million tons of coal.

CHAPTER XI

THE CARBONIZATION OF COAL

THE nature of the primary and secondary reactions associated with the carbonization of coal in closed retorts has occupied the attention of the scientist and investigator for nearly a century; yet, although, to-day, we are in a position to understand several of the more perceptible developments accompanying this phenomenon, there still remain many anomalies on which light has to be shed. The results of carbonization, and the final mode of existence of the innumerable products yielded, are materially influenced by considerations other than that of the temperature at which distillation occurs, so that it is impossible to form an opinion as to ultimate effects until the exact conditions under which the process is carried out are known.

The distillation of coal is usually characterized as "destructive," but the term is in reality a misnomer, owing to the fact that it implies finality; this only being the case so far as the original structure and substance of the raw material are concerned. The distillation of coal differs from that of a complex liquid in that the treatment of the latter is carried out in a number of stages, depending upon the original nature of the substance and the character of the products required. With the liquid, "fractionation" essentially occurs, whereas coal is dealt with in a single stage, innumerable products being simultaneously evolved and no attempt being made, in the first instance, to separate out the various compounds. A further fact of interest is that with coal, once distillation has occurred, there is no possibility of reproducing the original substance by collecting the products and causing them to recombine. In the case of a complex liquid, however, the various fractions may be remixed, when a substance more or less in accordance with the original substance will result.

The four fundamental bases of which the coal conglomerate is considered to exist are fully discussed in the previous chapter, and it is there pointed out that when subjected to distillation each of these bases gives rise to its own particular degradation products. Lewes, in his researches, found evidence that the primary decomposition of the coal substance accounts for the various constituents in the following manner:—

	Gaseous Products.	Liquids.	Solids.
Humus bodies, yield . .	Carbon monoxide Carbon dioxide Methane	Water Thin tar	Free carbon
Resin bodies, yield . . .	Carbon monoxide Carbon dioxide Ethylene, and unsaturated hydrocarbons	Water Rich tar	Free carbon Pitch
Hydrocarbons, yield . . .	Methane, ethane and other paraffins	Heavier tars	Free carbon Pitch

Carbon Residuum. *Unaffected by distillation*

In the study of carbonization it is essential, in the first place, to distinguish between the primary and secondary products of distillation, and to bear in mind that, in spite of the ultimate gas containing about 50 per cent. of hydrogen, this element, *per se*, is not evolved from the coal in the early stages, but results from the degradation of carbon and hydrogen compounds, and to some extent from the production of water gas. The lowest temperature at which carbonization occurs varies between 570° and 750° Fahr., when chiefly hydrocarbons of a condensible nature are evolved, the permanent gas yield being comparatively small. At such temperatures primary products alone would be expected, but even at this stage some secondary decomposition will have occurred, so that a series of products of a purely primary nature will not be found. Low temperature distillation in the absence of degradation would account for the following, which constitute the true primary gas :—

1. Water vapour.
2. Carbon dioxide and carbon monoxide.
3. Hydrocarbons of the paraffin series.

The bulk would be made up of these, whilst, in addition, there would be smaller quantities of :—

4. Unsaturated hydrocarbons.
5. Ammonia.
6. Sulphuretted hydrogen.

A large proportion of the paraffin hydrocarbons would be of a condensible nature, accounting for tar rich in the methane hydrocarbons. From the above it will be seen that the water vapour and oxides of carbon are the first products to be evolved, and that of the primary constituents methane is by far the most important.

THE ELEMENTS IN COAL AND THEIR RELATION TO CARBONIZATION

Of the elements in coal, carbon is present in the greatest proportion, partly fixed and partly capable of volatilization. In the ordinary way from 15 to 20 per

cent. of the total is present in the "free" state, and the actual distribution has been shown to be somewhat as follows:—

DISTRIBUTION OF CARBON IN COAL

(*a*) As hydrocarbons	8	per cent.	of total	carbon.
(*b*) As carbon monoxide and dioxide	2–3	„	„	„
(*c*) As tar	8	„	„	„
(*d*) Remaining in coke	80–85	„	„	„
(*e*) Other sources, such as "scurf"	1	„	„	„

From the gas-making point of view the carbon and hydrogen are the two most important constituents. The hydrogen passes off partly in combination with oxygen as steam, and partly combined with carbon to form hydrocarbons of both the saturated and unsaturated series. By far the largest quantity, however, is found as free hydrogen in the gas. A certain proportion of the hydrogen remains behind in the coke, but with the modern tendency to conduct carbonization at extremely high temperatures, little can withstand the final stages of the period, and the amount so remaining seldom exceeds 0·5 per cent.

Although the solid residue left behind in the retort contains a greater proportion of carbon and less hydrogen than the original coal, the reverse is the case with the volatile portion, which shows a preponderance of hydrogen. The constitution of this volatile portion largely depends upon the temperature prevailing. As a general rule the volume of permanent gas obtained is in direct ratio to the temperature employed, whilst the quality varies inversely with the temperature. Of the carbon and hydrogen compounds, those evolved at the lower temperatures of carbonization are mostly condensible at ordinary temperatures, and the permanent gas obtained consists mainly of methane, ethane and ethylene; that is to say, hydrocarbons of the paraffin and olefiant series. In addition, a small proportion of hydrogen due to secondary reaction will be present. The liquid products will be largely of a paraffinoid nature. It is during the early stages of carbonization that the more valuable constituents are evolved, and as the temperature throughout the entire mass gradually rises to the present limit of about 2,000° Fahr. the volatile products are composed mainly of methane and hydrogen, the proportion of the former diminishing and of the latter increasing as the period proceeds, until finally little more than the residual hydrogen and nitrogen of the coke remain to be expelled. Owing to the thickness of the modern heavy charge the heat penetrates to the interior of the mass comparatively slowly; accordingly hydrocarbons and gases of a primary nature are continuously being evolved until the central cool core is carbonized through. Portions of these primary gases, however, only exist momentarily. They undergo degradation into simpler compounds on coming into contact with the heated coke, and are further decomposed whilst travelling along the free space to the outlet of the retort. For this reason it is advantageous to distinguish between not only primary and secondary products, but also between primary, secondary and tertiary effects. That is to say, to consider the ultimate substances obtained to consist of:—

(*a*) True primary products escaping further degradation.

(*b*) Secondary products resulting from decomposition due to passage through the hot coke mass.

(*c*) Tertiary products resulting from the further degradation of secondary products owing to the exposure of the latter to radiant heat and to hot surfaces during their passage from the retort.

It is the hydrocarbons of both the saturated and unsaturated series which are chiefly affected by these further influences, but oxygen-bearing substances and nitrogen compounds also undergo some change.

In addition to being present in the coal substance, oxygen is derived in some quantities from the moisture in coal, the latter varying from 4 to 10 per cent. This moisture is in the main detrimental to the process of carbonization, in that it tends to reduce the temperature of the retort owing to the large quantity of latent heat absorbed in converting the water into steam. In the earlier stages the oxygen of the coal, as distinct from that emanating from the moisture, is evolved largely as oxides of carbon, whilst on combination with the hydrogen some portion will give rise to water. Colman is of the opinion that the oxygen is originally evolved as volatile compounds of carbon, hydrogen and oxygen, and that these on further heating are decomposed into carbon monoxide, carbon dioxide and steam. Whatever the manner of formation of the oxides of carbon, however, it is quite evident that the carbon dioxide, during its passage through the outer coke layers, tends to combine with the red-hot carbon, undergoing conversion into carbon monoxide. In this way secondary reaction is responsible for an increase in the combustible gases at the expense of an inert and useless diluent. The greater the temperature of distillation the more pronounced will this interchange be.

Of the oxygen present in coal the greater portion combines with hydrogen to yield steam, about 25 per cent. exists as oxides of carbon, and a small proportion is found as compounds of hydrogen and carbon, such as the phenols, etc., in the tar. So far as the steam derived both from the original moisture in the coal and from the direct combination of hydrogen and oxygen is concerned, the greater proportion of this will eventually condense out as water, whilst some portion will account for the formation of water gas during its passage through the heated coke. It will be seen, accordingly, that the importance attached in the past to the " unoxidized hydrogen " content of a coal was much over-estimated, for an appreciable portion of the oxygen of the coal substance is disposed of in other ways than by direct combination with hydrogen.

The Nitrogen of Coal

The element nitrogen, although of more or less subsidiary importance, enters materially into the reckoning when the economics of carbonization come to be considered. The aim of the gas engineer must be to recover in the most valuable form the largest possible proportion of the total nitrogen present, which on further treatment forms the basis of one of his most valuable by-products, sulphate of ammonia. The amount of nitrogen in bituminous coals is, on the whole, the least variable of

any of the constituents, the figure fluctuating but little on either side of 1·4 per cent. This percentage corresponds with a yield of about 34 lb. of nitrogen per ton of coal employed, whilst the average yield of sulphate of ammonia, amounting to 27 lb. per ton, represents a quantity of ammonia equal to 7 lb., or about one-sixth of the total nitrogen. In addition, a small portion may be usefully recovered in the form of cyanide compounds; but comparatively few gasworks are provided with the necessary plant for this purpose. For some years attention has been directed towards the possibility of recovering a greater proportion of the original nitrogen, but although plants for the production of low-grade gas are operating successfully in this direction, the conditions under which the increased yield is obtained are scarcely consistent with ordinary gasworks methods. As an instance, mention may be made of the Mond gas apparatus, by means of which an average yield of 96 lb. of sulphate of ammonia is obtained, this quantity representing nearly 25 lb. of recovered ammonia, or about 65 per cent. of the total nitrogen.

One of the earliest attempts to determine the relative quantities in which nitrogen is distributed among the various products was made by Foster, in 1883. This investigator employed a Durham coal containing 1·73 per cent. of nitrogen, and the conclusions arrived at are as follows:—

Nitrogen remaining in coke	48·68	per cent. of total.
„ free in gas and combined in tar	35·26	„ „
„ as ammonia	14·50	„ „
„ as cyanogen	1·56	„ „

Investigation of this kind is attended by considerable difficulties, and several other workers have derived figures on the same lines, but in no case are they in close agreement. The researches of McLeod, conducted in 1907, are, however, considered most trustworthy, having been carried out under everyday conditions. McLeod's figures are as follows:—

Nitrogen in coke	58·3	per cent.
„ free in gas	19·5	„
„ as ammonia	17·1	„
„ as tar	3·9	„
„ as cyanogen	1·2	„

The figures which Short obtained for conditions existing in coke ovens are instructive, in that, with the present tendency towards mass carbonization in gasworks, they probably approach more nearly the actual state of affairs. Short's researches show the following distribution:—

Nitrogen in coke	43·3	per cent.
„ „ tar	3·0	„
„ „ ammonia	15·2	„
„ „ cyanogen	1·4	„
Free nitrogen in gas	37·1	„

In all cases the results conclusively show that by far the greater proportion of nitrogen remains behind in the coke; but with the prolonged periods and high temperatures of modern distillation methods the proportion remaining in the solid

residue is undoubtedly far less than was the case some few years ago. The effect of a long-sustained heat such as exists with the present-day 12-hour charge was shown by Watson Smith to be conducive to the most complete expulsion of the nitrogen from the coke, and he found in the case of coke-oven coke (which is essentially subjected to this type of heating) that the nitrogen percentage was only 0·384.

It would appear that in all cases the figures given for the nitrogen distributed as cyanogen are considerably below those prevailing in modern practice. At the present time there are many cyanogen plants at work recovering on an average from 4 to 5 lb. of ammonium sulphocyanide per ton of coal, these quantities of sulphocyanide representing from 0·75 to 1 lb. of nitrogen, or nearly 3 per cent. of the total nitrogen. As nitrogen, however, is drawn in from the atmosphere and furnace it is possible that a portion of the nitrogen combined in the cyanogen is obtained from such external sources. The nitrogen combined in tar is chiefly present in the form of nitrogenous bases such as pyridine.

It will be realized that if it were possible to recover the whole of the original nitrogen in coal as sulphate of ammonia the yield of sulphate would approximate to 180 lb. per ton of coal carbonized.

A good deal of uncertainty exists as to the type of coal which is likely to prove the most efficient producer of ammonia. Schilling, for instance, says that the amount of ammonia yielded rises and falls according to the quantity of nitrogen in the coal. Knublauch is of the opinion that the coals which give very high yields of gas and tar have a tendency not to form ammonia, the hydrogen uniting with the carbon, whilst the coals which account for high ammonia yields show an inclination to leave the nitrogen in the coke and not to form free nitrogen in the gas. More important considerations, however, do not permit of a coal being purchased on its nitrogen-yielding proclivities alone.

With regard to the formation of ammonia, there is now little doubt that it is the direct result of two distinct reactions, and that whereas the chief of these takes place at lower temperatures, the second is probably most in evidence at higher heats. Accordingly, ammonia resulting from distillation may be formed :—

(*a*) By direct evolution from an ammonia yielding body contained in the coal.

(*b*) Synthetically, by the combination of hydrogen and residual nitrogen.

Little is known as to the actual mode of existence of the nitrogen compounds in coal, but there is evidence to show that the element is combined in two or more ways. Lewes is of the opinion that the humus bodies are most likely to be those carrying the nitrogen. So far as the coke is concerned, Harger says the only conclusion he could arrive at, after careful consideration of all the facts, was that some of the nitrogen in the coke is present as one or more stable organic nitrogen ring compounds.

Under the influence of distillation ammonia is one of the first compounds to be expelled, the evolution commencing at temperatures between 600° and 750° Fahr., and continuing up to about 1,000° Fahr., when the whole of the primary portion appears to be evolved. Little or none is given off as the temperature rises from 1,000° Fahr. to 1,600° Fahr.. but beyond the higher temperature further appreciable

quantities are discernible. Accordingly, the maximum yield of ammonia is obtained only when the distillation temperature has reached 1,600° Fahr. or slightly over. The possibility of an easily decomposible compound being able to exist at this temperature is explained by the fact that if an unstable gas be diluted with some considerable quantity of inert gas the temperature necessary to bring about decomposition increases rapidly in proportion with the amount of dilution. Thus the ammonia is quickly exhausted away from the retort before feeling the effects of degradation. It is in this manner that the high yield of ammonia in the Mond plant may be explained, for an excess of steam and air is admitted to the base of the fuel bed and forms an enveloping gaseous mass (containing a high percentage of inert constituents) which shields the ammonia on its passage through the producer.

The production of the secondary ammonia, as distinct from that evolved as a primary compound, has been explained by Tervet, who states that a portion of the nitrogen remaining in the coke can be liberated in the form of ammonia, so long as the ammonia is brought into a state of strain which shall prevent it from subsequent degradation. This state is effected by subjecting the ammonia to the superior affinity which exists between the combined nitrogen in the coke and free hydrogen at a particular temperature and in a diluting atmosphere. Thus synthesis between the free hydrogen in the retort and the nitrogen evolved from the coke at higher temperatures is taking place.

Important work on the question of the effect of temperature and other conditions on the yield of ammonia has recently been carried out by Cobb and Hollings, who are still engaged in the research. In their experiments these investigators have studied the decomposition of the ammonia from coal when the products are subjected to differing conditions. In each case a small quantity of coal was distilled in a boat contained in a specially sealed and heated tube, and the ammonia present in the products was estimated. The gases evolved from the coal were first drawn away from a tube which was so designed and arranged that secondary reaction had no time to exert its influence; in the second series of experiments they were drawn through a heated tube and subjected to radiant heat; whilst, thirdly, the tube was packed with coke, and the gases drawn through this. The results of their experiments may be briefly tabulated as follows:—

(a) Minimum heat action . . 22·5 per cent. of nitrogen in coal recovered as ammonia.
(b) Gases subjected to radiant heat 17·2 „ „ „ „ „
(c) Gases passed through hot coke 9·4 „ „ „ „ „

From these figures conclusions can be drawn as to the effect of high temperatures and travel over heated surfaces on the yield of ammonia. The temperature of 800° C. (1,470° Fahr.) was used throughout.

The effect of the heavy charge of long duration in ensuring the gases being swept from the retort before decomposition has occurred to any extent is shown by the following figures given by Ferguson Bell:—

6-hour	charges of	6	cwts.	of	coal,	yield of	ammonia	7·26	lb. per ton.
8-hour	„	7¾	„	„		„	„	8·26	„ „
10-hour	„	9½	„	„		„	„	8·45	„ „
12-hour	„	11½	„	„		„	„	8·50	„ „

The small portion of the original nitrogen of the coal which is found as cyanides is almost wholly in the form of hydrocyanic acid, although small quantities of free cyanogen are also present. Hydrocyanic acid is essentially a high temperature product, and probably makes no appearance in the retort below temperatures of 1,600° to 1,700° Fahr. When higher temperatures were first introduced in conjunction with the light 6-cwt. coal charge a distinct increase in the yield of cyanogen was noticeable, whilst the yield of ammonia showed some falling off. There seems little doubt that the greater portion of the cyanogen is produced at the later stages of the charge, when the temperature is at a maximum, and the traces of synthetically produced ammonia which may be coming away have few diluent gases to shield them from decomposition. It is at these higher temperatures that a portion of the ammonia is split up into its elements hydrogen and nitrogen which react with carbon and yield hydrocyanic acid. It does not necessarily follow, however, that a high yield of cyanogen means a decreased production of ammonia, and in many cases a high yield of both products is obtained.

Some investigators, such as Kulmann, have shown that if carbon monoxide and ammonia are passed over spongy platinum a small quantity of hydrocyanic acid is formed, and this has led to the supposition (probably erroneous) that cyanogen may be formed in some degree by the double decomposition of carbon monoxide and ammonia. Others support the theory that ammonia and carbon disulphide react to form the product. It must be remembered that, like ammonia, hydrocyanic acid itself is liable to decomposition at the higher temperatures, and that the quantities in which it is ultimately found probably depend to some extent upon the amount of diluent gases which conduct it safely from the retort.

As regards the decomposition of ammonia, Bueb carried out a series of experiments which showed that at temperatures of about 1,400° Fahr. approximately 4 per cent. of the nitrogen of the ammonia was converted into cyanogen, whereas at 1,800° Fahr. nearly one-quarter of the amount had undergone this change. A somewhat remarkable result was obtained by Cobb and Hollings in connexion with hydrocyanic acid. In the experiments previously quoted, after decomposition of ammonia had taken place the products were tested for cyanogen, but in no case could the presence of this compound be detected. This is probably explained, however, by the fact that the conditions favourable to the production of cyanide were absent.

Several attempts have been made to increase artificially the recoverable proportion of the total nitrogen in coal, but their measure of success has been such that the suggested methods have only been adopted on gasworks in isolated instances. Among them may be mentioned the liming of coal, originated by Cooper, and now in constant operation at the Cheltenham gasworks. In this process lime is charged with the coal into the retorts. In order that thorough admixture may take place the coal is slightly damped on the surface by a steam jet, thus causing the lime to cling to the lumps. The quantity of lime intermixed with the coal is usually about 2 per cent. As a result of its employment the sulphate of ammonia recovered per ton of coal carbonized shows an average increase of nearly 2 lb. The improvement

in the yield of ammonia in this case is due to the fact that admixture of a caustic alkali has some tendency to convert the residual nitrogen of the coke into ammonia.

Some thirty years ago a method was discovered of extracting nitrogen in the form of ammonia from the coke of shale retorts, by passing steam through the fuel bed whilst in a highly heated condition. In this way the recovered ammonia increased by about 200 per cent. Several suggestions were made for the application of the same principle to the recovery in the form of ammonia of the nitrogen left behind in the coke produced on gasworks. One promising suggestion provided for dropping the red-hot coke as it came from the retorts into special chambers maintained at a high temperature into which—for a short period—steam could be blown. A certain quantity of blue water gas is thus obtained, and at the same time a large additional yield of ammonia. Another means was based on the fact that when hydrogen, or a gas rich in hydrogen, is passed through highly heated coke the hydrogen combines with the latent nitrogen to form ammonia. Such conditions are obtained by blowing water gas into the retort towards the end of the charge. This scheme has been tried on several works, and is now in operation at a few. The chief objection to it is the degree to which the illuminating power of the final gas is reduced. So far as gasworks are concerned the many suggestions for recovering a greater proportion of the nitrogen of coal have as yet led to no satisfactory result; but the problem is of deep concern to the gas engineer and should not be allowed to rest.

The Sulphur of Coal

A portion of the sulphur present in the coal substance is of a more or less "fixed" nature and remains behind in the coke. This portion is usually present in the original coal as calcium sulphate, whilst the volatile sulphur is chiefly derived from pyrites and certain organic sulphur compounds. Coals as commonly used for gas-making contain a percentage of sulphur varying from 0·6 to 1·2, and that remaining behind in the coke, under modern conditions of carbonization, seldom exceeds 0·8 to 1 per cent. As previously pointed out, sulphuretted hydrogen is a primary product of distillation, and is one of the first products to be evolved. Colman says that the sulphur probably comes off in the first place as volatile compounds of carbon and hydrogen, and that these, when more strongly heated, yield sulphuretted hydrogen. A small quantity of sulphur, hydrogen and carbon compounds are, however, ultimately obtained, as an instance of which may be mentioned thiophen (C_4H_4S). This is frequently found in the tar, although traces of it are usually present in the small percentage of sulphur compounds in the finished gas.

The sulphur compounds, as distinct from sulphuretted hydrogen, are chiefly formed at the higher temperatures, due to the combination of part of the sulphur with carbon. The higher the temperature of distillation the greater will be the quantity of sulphur driven off from the coke, and extended travel of the gas through heated coke or in contact with hot surfaces accounts for the decomposition of sulphuretted hydrogen and the subsequent formation of carbon disulphide. Accord-

ingly, when secondary reaction at high temperatures is permitted to take place the easily removable sulphuretted hydrogen gives place, in part, to undesirable compounds, such as carbon disulphide, which are only eliminated from the gas with great trouble. Sulphuretted hydrogen is usually present in the crude gas in the proportion of about 1·5 per cent., whilst the other sulphur compounds together total no more than 0·05 per cent.

DISTRIBUTION OF ELEMENTS IN COAL AND GAS.

Below is set out a table showing the *approximate* distribution of the elements in a ton of coal and the manner in which each element exists after the process of carbonization. The table is, of course, merely illustrative, and does not do more than give a general indication of the lines on which the rearrangement of the elements takes place. It is assumed that no loss has taken place and that no other products have been introduced.

1 Ton of coal.	
Consisting of:—	
1,792 lb. *carbon*.	
Distributed as coke	1,385 lb.
„ as breeze	107 „
„ in gas, as CO, and CO_2	30 „
„ in gas, as hydrocarbons	130 „
„ in tar	122 „
„ as scurf, cyanide, etc.	18 „
123 lb. *hydrogen*.	
Distributed in gas and tar	98·5 „
„ as ammonia	1·0 „
„ as water	18·5 „
„ in coke	5 „
197 lb. *oxygen*.	
Distributed as CO, CO_2 and combined in tar	49 „
„ as water	148 „
34 lb. *nitrogen*.	
Distributed in gas (free)	11·8 „
„ in coke	14·1 „
„ in tar (combined)	1·0 „
„ as ammonia	5·8 „
„ as cyanogen (total HCN 4 lb.)	1·3 „
18 lb. *sulphur*.	
Distributed as gaseous impurities and in liquor	6 „
„ in coke	12 „
76 lb. *ash* remaining in coke and breeze	76 „
2,240 lb.	**2,240 lb.**

The yield given for water amounts to 166⅔ lb.(148 lb. from oxygen and 18·5 from hydrogen), this being equivalent to about 16 gallons of virgin liquor. No allowance, however, has been made for the steam which is converted into water gas. In the ordinary way, from 10 to 12 gallons of condensed water, or virgin liquor, are obtained, the remainder being decomposed in contact with the hot coke.

A comparison between the chemical constitution of the solid substance before and after distillation, *i.e.*, the contrast between coal and coke, is shown as follows :—

Before Distillation. Coal.		After Distillation. Coke.	
80 per cent.	carbon	88·0 per cent.	
5·5 „	hydrogen	0·2 „	
8·8 „	oxygen	traces to 3·0 „	(very variable)
1·5 „	nitrogen	2·0 „	
0·8 „	sulphur	1·0 „	
3·4 „	ash	5·8 „	

THE HYDROCARBONS

Before studying the hydrocarbons it is of advantage to have a clear conception of what is understood by the valency of the elements. All elements have a certain power of combining with other elements, and many can exert this power either wholly or in part. When chlorine and hydrogen unite, one atom of the chlorine combines with one atom of hydrogen to give a molecule of hydrochloric acid. But when oxygen unites with hydrogen, one atom of oxygen takes up two atoms of hydrogen. Furthermore, ammonia is composed of one atom of nitrogen in conjunction with three atoms of hydrogen ; whilst one atom of carbon is capable of combining with four atoms of hydrogen (*e.g.* CH_4). Thus one atom of some elements unites with one atom of others, some take up two, some three, and so on, before they are fully satisfied or "saturated." Once, however, the requisite number has been absorbed, then the original atom can unite with no more. Elements differ considerably as to their powers of combination, and it is proposed to consider briefly here only those most important in gas-making, and, chiefly, the combining powers of carbon with hydrogen, oxygen and nitrogen.

Carbon is "tetravalent," *i.e.*, one atom unites with four atoms of a "monovalent" element or two of a "divalent" element, or two atoms of a monovalent element and one of a divalent element.

Hydrogen is monovalent, *i.e.*, one atom combines with only one atom of a monovalent element.

Oxygen is divalent.

[1] Nitrogen is trivalent.

Carbon is tetravalent.

Chlorine is monovalent.

[1] Sulphur is divalent.

Carbon differs from other elements in forming an abnormally large number of compounds with hydrogen—called hydrocarbons. The simplest is methane (CH_4). The various compounds are classified as "saturated" and "unsaturated," according as to whether the carbon atoms are (owing to their tetravalent nature) fully saturated or not. When hydrocarbons are arranged in order of molecular weights, they comprise a series, each member of which contains so many atoms of carbon and hydrogen more than the preceding member. For example :—

[1] Nitrogen and Sulphur have varying valencies.

Methane, CH_4		
Ethane, C_2H_6	difference	CH_2
Propane, C_3H_8	,,	CH_2
Butane, C_4H_{10}	,,	CH_2
Pentane, C_5H_{12}	,,	CH_2,

etc.

Such a series, of which the members undergo a constant and gradual variation, is known as a homologous series, and the several members are denoted as homologues of one another. The above series, it will be seen, can be expressed by the general formula C_nH_{2n+2}. The chief homologous series of hydrocarbons of assistance in studying the chemistry of carbonization are the following :—

(1) The paraffin series.
(2) The olefines, or ethylene series.
(3) The acetylenes.
(4) The benzene or aromatic series.

The more important members of these series are given below :—

I.	II.	III.	IV.
Paraffin (C_nH_{2n+2})	Olefines (C_nH_{2n})	Acetylenes (C_nH_{2n-2})	Benzenes (C_nH_{2n-6})
Methane, CH_4	—	—	—
Ethane, C_2H_6	Ethylene, C_2H_4	Acetylene, C_2H_2	Benzene, C_6H_6
Propane, C_3H_8	Propylene, C_3H_6	Allylene, C_3H_4	Tolnene, C_7H_8
Butane, C_4H_{10}	Butylene, C_4H_8	Crotonylene, C_4H_6	Xylene, C_8H_{10}
Pentane, C_5H_{12}	Amylene, C_5H_{10}	Etc.	Etc.
Etc.	Etc.		

AROMATIC AND ALIPHATIC COMPOUNDS.

The benzene series was originally called the aromatic series, owing to the fact that the first hydrocarbons discovered were obtained from aromatic balsams and resins. Thus by "aromatic derivatives" are meant compounds related to the benzene series. The term aliphatic or "fatty" derivates has reference to those substances associated with the paraffin or methane series.

STRUCTURAL FORMULÆ

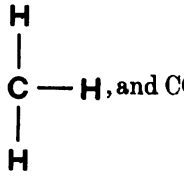
It has already been mentioned that carbon is a tetravalent element, *i.e.*, one atom can combine with

(*a*) 4 atoms of a monovalent element, *e.g.* CH_4.
(*b*) 2 atoms of a divalent element, *e.g.* CO_2.
(*c*) 1 divalent and 2 monovalent atoms, *e.g.* $COCl_2$.
(*d*) 1 trivalent and 1 monovalent atom, *e.g.* HCN.

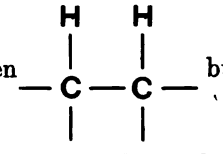
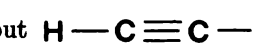
With the exception of carbon monoxide (CO) no compound containing only one carbon atom is known in which the carbon atom is combined with either more or less than four monovalent elements or their valency equivalent. It must be pointed

out, however, that Professor Bone has concluded that certain residues such as CH and CH_2 may have a very brief existence under definite influences.

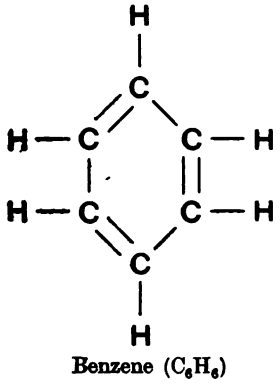
Many cases are known in which two or more compounds have the same molecular formula, but differ considerably in chemical and physical properties. For instance, there are three distinct compounds bearing the formula C_5H_{12}, and two having the molecular formula of $C_2H_4O_2$. Owing to the differing characteristics of these substances, it is only natural to conclude that whilst as regards the number of atoms of the various elements composing the molecule they are similar, these atoms are differently arranged and give rise to a variation in constitution. On this account suitable formulæ (known as structural formulæ) have been devised to express more clearly the behaviour and constitution of the compound. Instead of denoting

methane by CH_4 we can write  , and CO_2 may be expressed as O=C=O.

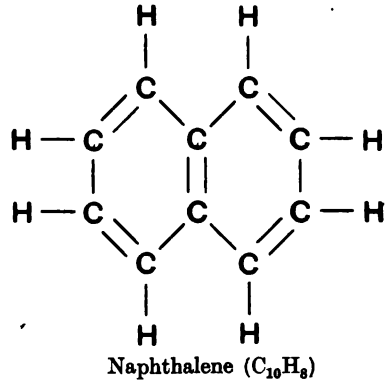
In each case it is seen that the tetravalent nature of carbon is shown by four affinities or bonds exerting an attractive force between it and the other atoms. The single valency of the hydrogen atoms and the dual valency of the oxygen atoms are also correctly expressed. Such methods of indicating the constitution of chemical substances are of extreme value in studying the degradation of the less stable hydrocarbons during the distillation of coal in the retort. In the case of the unsaturated compounds the carbon atoms are assumed to exert an affinity on one another, thus

acetylene (C_2H_2) is not written  but  . Thus

double or treble bonds exist between the carbon atoms. Compounds such as acetylene, with structural formulæ on the same lines, are known as open chain compounds, whereas in more complicated substances a closed ring may result. Notable instances of the latter are the benzene and naphthalene rings given below.

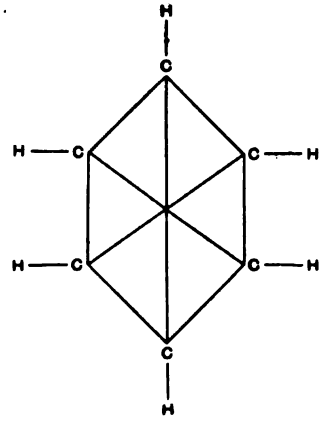


Benzene (C_6H_6)



Naphthalene ($C_{10}H_8$)

Owing to the impossibility of depicting the true arrangement of such compounds on a flat surface (the actual arrangement taking place in space) some prefer to avoid the use of double or multiple bonds and to place the surplus affinities within the ring. Thus, benzene is denoted by—



THE DEGRADATION OF THE HYDROCARBONS

The secondary reactions which take place during the carbonization of coal have been the subject of an unusual amount of research. The variable and complicated conditions under which these changes occur, however, render the path of the investigator extremely difficult. When a comparison of results is made, therefore, it is not surprising to find the expression of a number of contradictory opinions, although with regard to many of the more important facts a certain amount of uniformity is displayed. Primarily, it is recognized that when subjected to certain severe influences many of the less stable products evolved from coal are unable to withstand their tendency to decompose, with the result that they are split up into more stable compounds of a similar nature. This degradation or reconstruction chiefly applies to the carbon and hydrogen compounds, although—as previously shown—substances (such as ammonia and carbon dioxide) composed of other elements are by no means immune. It must be recognized that in order to obtain the maximum yield of gas from a definite bulk of coal it is not sufficient to submit the solid mass alone to a very high temperature, but the primary volatile products must afterwards come under the influence of further heat, so that some portion of the condensible vapours will be converted into permanent gas. Moreover, whereas there is no limit of temperature beyond which it might be inadvisable to heat the solid residue, the same does not apply to the primary products, as too great exposure to intense heat has detrimental results in their case. In the gas retort this secondary reaction is occasioned by the passage of the products through the heated coke mass and during their travel to the exit of the retort in contact with the heated walls of the vessel. Accordingly, the extent to which the primary products undergo decomposition depends partly upon the limits to which the retort is heated, but in greater degree upon the manner in which the volatile products leave the retort and upon the time

spent in contact with the hot surfaces. Degradation, then, may be assigned to the following three causes :—

(*a*) The temperature to which the products are submitted.
(*b*) The nature of the solid surfaces to which they are exposed.
(*c*) The length of contact time with these surfaces.

When the decomposition is such as to be beyond the economical limit, "over-cracking" of the gases and vapours is said to occur. It will be seen that heat may be encountered by the products in two distinct ways—namely, by contact with the heated coke and retort walls and by direct radiation from the heated surfaces. Some years ago Young pointed out that the action of these two forms of heat is distinct; that whereas contact with the hot surfaces appears to act with more or less equal effect on all substances, the radiant heat tends to have a selective action, and most readily attacks those molecules which absorb heat the more easily. In the light of recent research, however, it would appear that this conclusion is by no means established; the most severe effects seem to occur during the passage of the products through the layers of red-hot coke. Chiefly, it is found that the heavy hydrocarbons, particularly the olefines, the acetylenes and the lower members of the paraffin series, are most prone to these influences, whilst the more stable methane is only affected by drastic conditions. The small proportion of rich gas present in the primary products consists largely of ethane and its homologues, ethylene and acetylene, and Colman states that the condensible compounds are relatively rich in hydrogen, and belong to those series in which the carbon atoms are united in open chains. If, however, they are present in closed chains, they are combined with much more hydrogen than is the case with the aromatic hydrocarbons, and are probably akin to the naphthenes and similar compounds. In their passage through the coke the primary gases ethane, ethylene, acetylene, and methane all tend to undergo decomposition, whilst the condensible products become partly gasified and altered in character to some extent. Accordingly, whilst a greater yield of permanent gas is obtained at higher temperatures, considerable deterioration in quality follows the breaking down of the richer constituents into less valuable products.

The comparative value of the various constituents so far as the illuminating and calorific powers of the ultimate gas are concerned is emphasized in the following table :—

	Calorific power (gross).	Candle-power.
Benzene	3,700 B.Th.U. per cubic foot	165 candles per foot
Ethane	1,870 „ „ „	7 „ „
Ethylene	1,600 „ „ „	10 „ „
Methane	1,020 „ „ „	1 „ „
Carbon monoxide	340 „ „ „	nil
Hydrogen	325 „ „ „	nil

With regard to candle-power the effect of methane is questionable. When burned by itself it appears to show but poor light-giving properties, but when present in an admixture such as coal gas it undoubtedly accounts for an increase in illuminating power out of proportion to that shown in the above table. Whatever its effect as an illuminant, however, methane—owing to its high calorific value—is one of the most desirable constituents of modern gas, and as calorific standards of quality gradually supplant the now obsolete candle-power test, methane will increase in importance. Fortunately, this hydrocarbon is the most stable of those present, and consequently suffers to a comparatively slight extent from the degrading influences in the retort.

One of the first investigators to turn his attention to the decomposition of gases was Berthelot, who, in 1863, carried out a number of experiments with the hydrocarbons. Previous to Berthelot's work it had been shown by other research that the ultimate resolution of a hydrocarbon into its elements, hydrogen and carbon, can in no way be regarded as the immediate result of a single change, but that gradual breaking down into molecules containing a smaller number of atoms takes place. Thus ethylene (C_2H_4) was considered to be resolved into free carbon and methane, and so on.

(*a*) Ethylene, $C_2H_4 = C + CH_4$.
(*b*) Ethane, $C_2H_6 = C_2H_4$ (ethylene) $+ H_2$.

The four hydrocarbons of chief interest to the gas engineer are the primary product ethane (which wholly disappears at present-day temperatures), ethylene, acetylene and methane. Berthelot, as a result of his studies, was of the opinion that these hydrocarbons underwent decomposition in the following manner :—

(*a*) Ethane, either (1) $C_2H_6 = C_2H_4$ (ethylene) $+ H_2$,
or (2) $2C_2H_6 = 2CH_4$ (methane) $+ C_2H_2$ (acetylene) $+ H_2$.

(*b*) Ethylene, either (1) $C_2H_4 = C_2H_2$ (acetylene) $+ H_2$,
or (2) $2C_2H_4 = C_2H_6$ (ethane) $+ C_2H_2$ (acetylene).

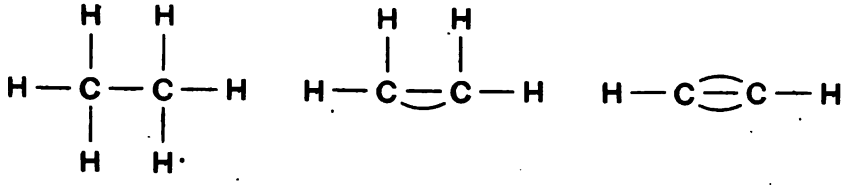
(*c*) Acetylene. This he concluded was never resolved into its elements, but was capable of undergoing polymerization or condensation into benzene at high temperatures. Thus $3C_2H_2 = C_6H_6$.

(*d*) Methane, either (1) $2CH_4 = C_2H_2$ (acetylene) $+ 3H_2$,
or (2) $2CH_4 = C_2H_6$ (ethane) $+ H_2$.

In 1894, Lewes, in a number of experiments on the hydrocarbons, of which he chiefly studied ethylene, concluded that this compound is primarily decomposed into equal volumes of methane and acetylene on the following lines :—$3C_2H_4 = 2CH_4 + 2C_2H_2$. With regard to methane he agrees with Berthelot that this is transformed into hydrogen and acetylene, but that the acetylene subsequently polymerizes or is resolved into its elements hydrogen and carbon. All are agreed as to the marked stability of methane. But that degradation of this constituent does take place at higher temperatures and under certain conditions is shown by

the manner in which the quantity has decreased in modern coal gas. Lewes states that for the methane to fall below 30 per cent. in a coal gas made from a good coal indicates degradation of the products by overheating, and, although decomposition to a certain extent is essential, it may be said that the economical limit is reached when the methane has been reduced to about 30 per cent.

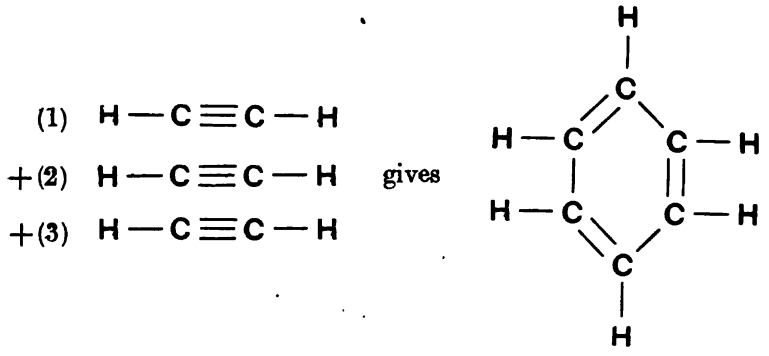
The tendency of hydrocarbons to dissociate is well illustrated by consideration of their structural formulæ and the arrangement of the carbon affinities. Thus we get—



Ethane (C_2H_6) Ethylene (C_2H_4) Acetylene (C_2H_2)

In each case it will be seen that the carbon atoms are not wholly saturated with hydrogen, and in order that each affinity may fulfil its properties of attraction the carbon atoms are indicated as attracting one another. A bond of this nature invariably gives rise to a state of instability, so that the molecule at this point tends to sever, and to recombine into two molecules with the addition of hydrogen. In the case of ethylene and acetylene this tendency becomes still more marked, as a double and treble bond exists between the carbon atoms. The force of attraction between the atoms virtually acts along a straight line, but in the case of these two compounds it may be looked upon as being bent from its proper path and curved round so as to unite with the other carbon atom. Hence a condition of strain is set up in the bond, which on but slight provocation straightens out and takes up another hydrogen atom. Where double or treble bonds exist they may be taken as an indication of instability; and the greater the number of bonds uniting the carbon atoms the greater will be the tendency to decompose. Bone supports this theory by showing that acetylene tends to break down across the triple bond, yielding free carbon and hydrogen, whilst if other hydrogen is taken up methane will be formed.

Of the light-giving hydrocarbons in coal gas, benzene (which is present to the extent of about 0·75 per cent.) is one of the most important. Its presence has been accounted for in various ways, but there is little doubt that it is a high temperature degradation product. This is amply shown by the fact that whereas modern gas and tar emanating from heavy coal charges are of a distinctly paraffinoid nature, the hydrocarbons from the lighter charges, which afford ample opportunity for "over cracking," contain a greater proportion of benzene derivatives. Many investigators have sought to prove that benzene is the direct result of the polymerization of acetylene. Thus three molecules of acetylene (united in open chains) undergo rearrangement to yield the closed benzene formation :—

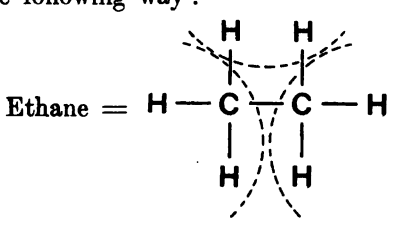


There is little doubt that such a reaction takes place to a certain extent, although, in the main, it seems probable that the benzene results at moderate temperatures from the paraffin derivatives. Bone has found that at low temperatures acetylene exhibits a strong tendency to polymerize, forming benzene, etc., so that when acetylene is the principal primary product in the decomposition of another hydrocarbon (for example, ethylene) there is always a marked secondary formation of benzene and other aromatic hydrocarbons. This tendency towards polymerization reaches its maximum between 1,000° and 1,300° Fahr. and practically ceases to exist above 1,800° Fahr.

With regard to the actual method of decomposition of the hydrocarbons the work of Bone (1908) may be looked upon as classical. This investigator has propounded entirely new theories, based on the fact that carbonaceous residues, such as CH and CH_2, are capable of an extremely fugitive existence. With the exception of methane, however, he is of the opinion that the mode of decomposition of any particular hydrocarbon cannot be expressed by means of a single chemical equation. The degradation of methane is, in the main, a direct disunion into carbon and hydrogen—$CH_4 = C + 2H_2$. The free carbon deposited from this reaction is of a hard and lustrous type, being wholly different from that resulting from the decomposition of the other hydrocarbons. So far as ethane and ethylene are concerned, the effect of high temperatures is to cause a dissolution of the bonds uniting the carbon atoms, thus giving rise to the residues ≡CH and =CH_2. Bone states that these residues may subsequently—

(1) Meet with other similar residues and form H_2C=CH_2 and HC≡CH.
(2) Break down directly into carbon and hydrogen.
(3) Are directly hydrogenized into methane.

These three reactions may occur simultaneously, depending upon the temperature, pressure, and amount of hydrogen prevailing. In the case of ethane, Bone represents the changes in the following way :—



The bond between the carbon atoms tends to break away, whilst two hydrogen atoms also escape, thus decomposing the molecule into three distinct portions, namely :—CH_2, CH_2, and H_2. Ethane then has yielded $[2(CH_2) + H_2]$ which on recombination may become either—

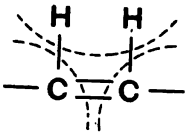
(1) C_2H_4 (ethylene) + H_2,

or (2) $2C + 2H_2 + H_2$,

and by hydrogenation, *i.e.* + H_2, we get—

(3) $2CH_4$ (methane).

In the same way ethylene has a tendency to split up across the double carbon bond into the following residues :—



Ethylene = $H-C\equiv C-H = [2(CH) + H_2]$.

These then reunite to yield—

(1) C_2H_2 (acetylene) + H_2 (hydrogen),

or (2) $2C + H_2 + H_2$,

or (3) by hydrogenation (*i.e.* + $2H_2$), = $2CH_4$ (methane).

With regard to acetylene, the change may take place either by polymerization, as already mentioned, or by dissolution into residues. In the latter case a weakness develops across the triple bond between the carbon atoms :—

Acetylene = $H-C\equiv C-H = 2\ (\equiv CH)$.

The CH residues then give—

(*a*) $2C + H_2$,

or (*b*) by hydrogenation (*i.e.* + $3H_2$) = $2CH_4$ (methane).

There is little doubt that in addition to degradation a certain amount of synthesis takes place at definite temperatures in the retort. The increase in the quantity of methane at higher temperatures is in all probability due to this cause. Burgess and Wheeler, in their well-known work, state that evolution of hydrocarbons of the paraffin series ceases almost entirely at temperatures above 1,290° Fahr. ; but at the same time there are certain indications of an increase in the methane above this point. Pring and Fairlie, in a contribution to the proceedings of the Chemical Society, state that results of their experiments show that at temperatures between 1,300° and 1,350° Fahr. acetylene reacts with hydrogen to give methane and ethylene. At a temperature of 2,200° Fahr. carbon was found to combine with hydrogen to give both methane and ethylene, the rate of formation of the methane being 100 times that of the ethylene. A certain amount of acetylene was also formed at this temperature, but the quantity was too small to be measured.

Some of the most enlightening work on the behaviour of the hydrocarbons has recently been carried out by Cobb and Hollings, at Leeds University. In this instance a small portion of coal was distilled in a boat and the volatile products

were subjected to various conditions. In the first case they were removed from the heated tube with the utmost rapidity; secondly, they were subjected to the radiant heat of the tube; and, thirdly, they were collected after passage through a heated coke surface. The results obtained go clearly to show that the last-named condition is attended by the most severe forms of degradation. A summary of these results is given here, and Table I indicates the percentage composition of the gas obtained under the different conditions.

TABLE I

PERCENTAGE COMPOSITION OF NITROGEN-FREE GAS

	Minimum heat action.	Radiant heat.	Hot coke surface.
	Per cent.	Per cent.	Per cent.
Unsaturated hydrocarbons	6·3	5·0	3·3
Methane	33·1	30·9	27·3
Hydrogen	42·5	46·6	51·2
Carbon monoxide	13·1	14·3	14·7
Carbon dioxide	4·3	3·4	3·2
Oxygen	0·7	0·1	0·5

At the same time the actual volume of each constituent obtained in cubic centimetres per gramme of coal was recorded. In Table II these figures have been reduced to cubic feet per ton—a measurement with which the gas engineer is more familiar.

TABLE II

YIELD OF NITROGEN-FREE GAS

	Minimum heat.	Radiant heat.		Hot coke surface.	
		Expt. I.	Expt. II.	Expt. I.	Expt. II.
Unsaturated hydrocarbons	538	525	563	287	472
Methane	3,157	3,552	3,444	3,516	3,588
Hydrogen	4,197	5,346	5,238	6,315	6,708
Carbon monoxide	1,614	1,614	1,471	2,045	1,937
Cubic feet per ton	9,506	11,037	10,716	12,163	12,705

It is seen that the result of subjecting the volatile products to the action of radiant heat is an increase of about 14 per cent. in "make" per ton, whilst by passage through the column of heated coke the increase amounts to 30 per cent. That the quality of the gas is lowered by the decomposition which has resulted from the further action of heat is shown by the reduction which has occurred in the propor-

tion of heavy hydrocarbons present. Hydrogen has increased in volume by 50 per cent., whilst methane remains moderately steady, showing that the extra hydrogen has not been obtained at its expense. The hydrogen appears to be chiefly the product of the decomposition of the heavy hydrocarbons and of the gasification of a portion of the tar.

Cobb and Hollings also conducted experiments on the decomposition of the various hydrocarbons in the presence of hydrogen and methane, and, therefore, under conditions approximating to those prevailing in a retort. A mixture was taken consisting of equal parts of hydrogen and methane to which were added small percentages of the hydrocarbons to be tested. Temperatures of 1,470° Fahr. and 2,000° Fahr. were selected for the study of decomposition, and only experiments in which the gases were passed through a tube packed with coke have so far been recorded. With regard to methane it was found that at 1,470° Fahr. only about 2 per cent. was decomposed in one minute, whereas at 2,000° Fahr. degradation is very rapid. In the latter case, however, there was an increase in volume of about 44 per cent.; but a considerable loss of calorific value was noticed owing to the carbon of the decomposed methane being deposited in the solid state. The results of the two experiments are shown below.

METHANE

		At 1,470° Fahr.	At 2,000° Fahr.
Gas before	Methane	50·9 per cent.	50·9 per cent.
	Hydrogen	49·1 „	49·1 „
Gas afterwards	Methane	49·5 „	6·6 „
	Hydrogen	50·5 „	93·4 „
Percentage of methane decomposed		2·8 „	87 „

So far as ethane is concerned it was found that the chief products of its decomposition are ethylene and methane. At 1,470° Fahr. the following results were noted after heating for forty-six seconds :—

ETHANE, at 1,470° Fahr.

Composition of gas.	Before.	After.
Ethane	4·2 per cent.	0·9 per cent.
Methane	47·5 „	48·9 „
Hydrogen	48·3 „	48·9 „
Ethylene	nil	1·3 „
Acetylene	nil	Trace

In this case the percentage of ethane decomposed amounts to 79, but at a temperature of 2,000° Fahr. the figure rose to 88 per cent.

Ethylene was found to show rather more stable properties than ethane, the

quantity decomposed at 1,470° Fahr. being 62 per cent. after heating for forty-five seconds, and at 2,000° Fahr. no trace of the product remained. The decomposition products consisted largely of hydrogen and methane, with a very small proportion of acetylene at the lower temperature.

The experiments with benzene are of particular interest in that they indicate the stable nature of this product at low and moderate temperatures and its complete instability at higher temperatures. At 1,470° Fahr. the decomposition was negligible, but at 2,000° Fahr. a very different result was obtained.

BENZENE, at 2,000° Fahr., heated for forty-two seconds.

Composition of gas.	Before.	After.
Benzene	5·0 per cent.	nil
Methane	47·8 „	11·1 per cent.
Hydrogen	47·2 „	88·4 „
Ethylene	nil	nil
Acetylene	nil	Trace

THE PROBLEM OF INCREASED YIELDS

Whereas a decade ago the gas engineer obtained little more than 10,000 cubic feet of gas from every ton of coal carbonized, to-day he is enabled, with the more efficient apparatus at his disposal, to swell this yield to as much as 14,000 cubic feet. This, however, would not have been possible but for the fact that the changing applications of gas have rendered the illuminating standard obsolescent, with the result that penal restrictions in this direction have been lowered. It is improbable that finality in regard to gas "makes" has yet been reached. Experiments conducted by Mr. Thos. Goulden appear to indicate that even higher results may be expected in the future. In tests with a Durham coal he obtained no less than 15,840 cubic feet of gas having the remarkably high calorific power of 530 B.Th.U. gross. In this case the illuminating power had dropped to twelve candles, but the most noticeable feature was the gradual advance of the heat units obtained in the gas as the volume increased. With the highest yield this increase amounted to no less than 15 per cent. as compared with the units obtained when the "make" was 12,000 cubic feet per ton. Without enrichment a gas of twelve candle-power would, of course, be unsuited for distribution in many areas at the present time, but with the advent of statutory requirements based on calorific power alone, it is possible that large yields such as this may become the fashion.

The chief points of interest are the means which have been employed in increasing the yield of permanent gas by so much as 40 per cent. Primarily, the introduction of the modern form of regenerative setting composed of material having greatly improved refractory qualities has rendered the first essential—the employment of high distillation temperatures—possible. The prolonged heating of the solid residue at temperatures of about 2,000° Fahr. is followed by the evolution of almost the

last traces of volatile matter, with the result that the constituents of present-day coke are almost wholly of a "fixed" nature. It must be realized, however, that the procurement of high makes of gas does not in any way depend solely upon the efficient burning-off of the charge, but is due to a combination of small influences, each of which requires expert and detailed supervision. On the average gasworks there are many insignificant items, probably unnoticed in the general way, which may account for some slight disorganization of working, and—as the engineer with record "makes" to his credit knows full well—it is the suppression of these and the maintenance of the whole machine up to concert pitch which tells its tale in the end. In addition to the higher heats of distillation now in use, the increased volume of gas may be ascribed largely to the following:—

(*a*) More complete gasification of tarry vapours, so that otherwise condensible products yield permanent gas.

(*b*) Increase of volume obtained by over-cracking the primary gas within the economical limit.

(*c*) The use of light seals, or no seals, in the "hydraulic" main, and the strict avoidance of tar seals.

(*d*) The employment in the hydraulic main of a vacuum slightly greater than the intensity of seal on the dip-pipe.

(*e*) The use of heavy charges of coal in the retort.

(*f*) Steaming the coal charge, as may be carried out in certain types of vertical retorts.

(*g*) The employment of prolonged charges in preference to those of short duration as used some few years ago.

(*h*) The discreet admission of air for the improvement of the process of purification, etc.

(*i*) Over-exhausting.

Nothing has been said with regard to the quality of coal made use of, this having some considerable influence on the final results. It is, however, a factor over which the average gas engineer has little control, it usually being necessary (on the grounds of economy) to take the coal from the nearest colliery.

It will be seen that the increased volume is composed chiefly of—

(*a*) Hydrogen, from the coke residue, from degradation, and from the gasified tarry vapours.

(*b*) Methane, from the gasified tarry vapours and from degradation of heavy hydrocarbons, also to some extent from synthetic sources at the higher temperatures. A portion of this methane is eventually decomposed, so that in the final gas it shows some deficiency compared with lower yields of gas.

(*c*) Nitrogen, from in-travel of the furnace gases, from the residual coke, which chiefly evolves this gas in the final stages, and from the atmosphere.

(*d*) Carbon monoxide, from the formation of water gas (particularly if "steaming" is practised), and from the reduction at high temperatures of carbon dioxide.

(*e*) Carbon dioxide, from the in-travel of furnace gases.

(*f*) Oxygen, from the atmosphere.

The effect of one important influence—that of over-exhausting—is admirably illustrated in the following table, in which the make in neither case is particularly high, but which gives an excellent indication of the manner in which the additional 800 cubic feet of gas per ton is accounted for :—

	Level-gauge in retort.	Over-exhausting.	Difference.
	Cubic feet per ton of coal.	Cubic feet per ton of coal.	
Hydrogen	5,676	5,709	+ 33
Methane	3,780	3,494	− 286
Carbon monoxide	1,164	1,254	+ 90
Carbon dioxide	264	346	+ 82
Heavy hydrocarbons	408	422	+ 14
Oxygen	60	90	+ 30
Nitrogen	648	1,485	+ 837
Total	12,000 cubic feet	12,800 cubic feet	+ 800
Candle-power	18	15	
Calorific power	575 B.Th.U.	559 B.Th.U.	

The table is compiled from percentage composition figures obtained by Dr. Davidson in distilling a standard second class Midland coal. The most noticeable results of the over-exhausting are a marked deficiency in the valuable heavy hydrocarbons and methane, whilst nitrogen has increased by 130 per cent.

The question as to the increase of volume of permanent gas obtained by over-cracking in the free space is a vexed one, and some authorities point out that the yield is swelled to only a meagre extent in this way. If we consider any of the degradation reactions, however, it is possible to show by means of Avogadro's law that some increase of volume does take place. For instance, if the reaction $CH_4 = C + 2H_2$ is taken as an example it is seen that one molecule of methane gives rise to two molecules of hydrogen. In other words, a cubic foot of methane yields on degradation double its volume of hydrogen ; that is, an increase of 100 per cent. in permanent gas. Similarly, ethylene (C_2H_4) may decompose into acetylene (C_2H_2) and hydrogen (H_2). Thus one molecule has yielded two molecules of gas ; again an increase in volume of 100 per cent. The extent of such decomposition, however, is relatively small in comparison with the total volume of gas present, and Lewes has shown that in the long run intentional over cracking in the retort will probably account for only an additional 400 or 500 cubic feet. Lewes' experiment on the effect of degradation of the primary products is of extreme interest. First, he obtained a semi-primary gas having an analysis approximately as follows :—

Hydrogen	27·5 per cent.
Saturated hydrocarbons—1, Methane	48·0 „
„ „ 2, Higher members	10·1 „
Unsaturated hydrocarbons	3·0 „
Carbon monoxide	7·3 „
Carbon dioxide	2·5 „
Nitrogen	1·6 „

This gas was then passed through a tube containing broken porcelain, and heated to 1,830° Fahr., when an increase of volume of 11 per cent. resulted, the composition then being as follows :—

Hydrogen	52·3 per cent.
Methane	34·0 „
Unsaturated hydrocarbons	2·5 „
Carbon monoxide	8·8 „
Carbon dioxide	1·0 „
Nitrogen	1·4 „

The original volume of semi-primary gas obtained amounted to 4,500 cubic feet, and this was swelled to 11,200 cubic feet by the second treatment. The most interesting feature of the experiment, however, is the manner in which the increased volume of gas is obtained. This is shown as follows :—

Volume composed of :—	
Primary gas	4,500 cubic feet.
Increase of volume due to degradation	495 „ „
Gas expelled from low temperature coke residue	5,000 „ „
Gas due to gasification of tar	1,205 „ „
Total yield	11,200 cubic feet per ton.

With regard to the final tar as yielded by Dessau vertical retorts, Davidson has shown that 1 gallon when gasified will produce 68 cubic feet of gas having a candle-power of 17·35. In the ordinary way the yield of tar from coal carbonized for prolonged periods at high temperatures varies from 12 to 14 gallons per ton, whereas with a gas make approaching only 5,000 cubic feet per ton the tar recovered would be in the neighbourhood of 20 to 22 gallons. The difference between these two figures represents the quantity of tar which under modern conditions is transformed into permanent gas and free carbon. The character of the tar is, moreover, considerably affected. When the gas has been subjected to the prolonged influence of secondary heat a tar of a distinctly benzenoid character results, whilst when the decomposition is limited—as with modern methods—the tar consists largely of derivatives comprised in the paraffin series.

The problem as to whether it is more profitable to aim at high tar yields and medium gas makes or abnormal gas makes and low tar yields is one upon which many and varying opinions have been given. It is of more than passing interest in that it really represents the distinction between the results obtained with horizontal and continuous vertical retorts. There can be little dispute that so far as gas yields are concerned the horizontal systems worked on efficient lines can more than hold their own, while the rival system presents many advantages in regard to tar, liquor, sulphur impurities, and, perhaps, naphthalene. The claim as regards naphthalene is one which requires a little qualification, for with the general adoption of the heavy charge in horizontal retorts naphthalene and stopped ascension pipes may be looked upon almost as things of the past, when ordinary precautions are taken.

The primary objection to intermittent systems of carbonization is the manner in which the quality of gas evolved undergoes deterioration as the period of distillation proceeds. Thus during the first quarter of an hour there is a burst of gas of good quality very much resembling the semi-primary gas given in the table on page 276. Although carried out some years ago, the experiments of L. T. Wright on the extent of deterioration still prove most instructive. The following figures obtained by Wright give an excellent idea of this effect :—

COMPOSITION OF GAS AT VARIOUS PERIODS OF CHARGE

	Period from Commencement (*Approximate*).			
	10 minutes.	1½ hours.	3½ hours.	5½ hours.
Hydrogen	20·10	38·08	50·68	67·12 per cent.
Methane	57·38	44·03	35·54	22·58 „
Heavy hydrocarbons	10·62	5·98	3·04	1·79 „
Carbon monoxide	6·19	5·98	6·21	6·12 „
Carbon dioxide	2·21	2·09	1·49	1·50 „
Sulphuretted hydrogen	1·30	1·42	0·49	0·11 „
Nitrogen	2·20	2·47	2·55	0·78 „
	100·00	100·00	100·00	100·00

The results were, of course, obtained at lower temperatures than those now prevailing, and under old-fashioned conditions of seal and vacuum, so that at the present day it would be unlikely that the nitrogen content would remain practically constant, and even show the reduction which Wright found after five and a half hours. In fact, in connexion with the heavy twelve-hour charge the author, in recent experiments, finds that with a ½-inch seal and 1½-inch "draw" the composition approximates to the following :—

	After 6 hours.	After 12 hours.
Hydrogen	45·2 per cent.	65·8 per cent.
Methane	22·9 „	1·4 „
Heavy hydrocarbons	4·1 „	nil
Carbon monoxide	6·3 „	15·2 „
Carbon dioxide	2·6 „	0·6 „
Nitrogen	18·0 „	16·6 „

So far as nitrogen only is concerned (determined by the direct method) the following figures are given as typical of those obtained under the rather severe and abnormal conditions quoted above :—

After 1 hour	11·6 per cent. of nitrogen.
„ 2 hours	14·8 „ „
„ 3 „	16·4 „ „
„ 4 „	16·7 „ „
„ 5 „	17·5 „ „
„ 6 „	18·5 „ „
„ 7 „	19·7 „ „
„ 8 „	20·1 „ „
„ 9 „	20·2 „ „
„ 10 „	15·9 „ „
„ 11 „	15·2 „ „
„ 12 „	15·2 „ „

In the modern form of coke oven it is customary to carbonize the heavy charges, amounting in some cases to as much as 10 tons, for periods of twenty-four hours, or even longer. Under such conditions the deterioration becomes somewhat excessive towards the end of the period, as is shown by the following results, obtained by Simmersbach for a twenty-nine hour charge.

Hour of carbonization.	2	3	4	5	6	7	8	9	10	11	12	13	15	17	19	21	23	25	27
Gas analysis.																			
CO_2	3·3	3·0	2·3	2·5	2·2	2·0	1·4	1·9	2·3	1·3	1·5	2·0	1·9	1·8	1·1	1·05	0·8	0·7	1·0
C_6H_6	1·8	1·5	1·1	1·1	1·0	0·8	0·6	0·5	0·35	0·35	0·35	0·3	0·25	0·1	—	—	—	—	—
C_2H_4	4·0	3·5	3·1	3·2	2·8	2·5	2·5	2·0	1·75	2·05	1·85	1·8	1·8	1·9	1·2	1·0	0·6	0·3	0·3
O_2	1·05	0·8	0·6	0·6	0·5	0·5	0·2	0·2	0·2	0·1	0·2	0·2	0·15	0·25	0·15	0·05	0·05	0·1	0·3
CO	0·9	1·9	2·9	2·8	3·0	3·95	3·4	3·1	2·8	2·8	4·15	4·1	3·9	4·15	4·7	4·0	3·8	4·9	5·8
CH_4	36·65	36·1	34·5	34·5	33·6	32·4	35·65	33·45	31·2	32·4	33·4	32·45	33·2	30·6	26·1	21·15	18·95	15·2	4·7
H_2	42·5	44·6	48·8	47·8	50·1	50·75	53·65	50·55	47·1	51·5	50·65	49·75	53·4	51·6	55·75	58·95	61·9	67·0	70·0
N_2	10·0	8·6	6·7	7·5	6·8	7·1	3·6	8·3	14·3	9·5	7·9	9·4	5·4	8·6	11·0	13·8	13·9	14·8	17·9

The coke yielded contained 2·56 per cent. of volatile matter and 88·53 per cent. of carbon. The nitrogen, it will be noticed, is at a minimum (3·6 per cent.) at the eighth hour, but is five times this amount at the twenty-seventh.

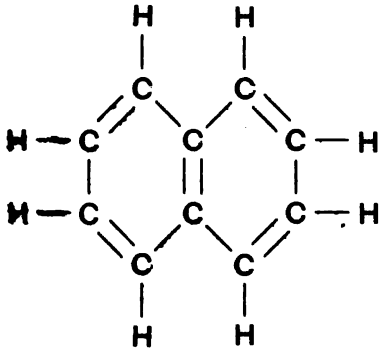
LIGHT AND HEAVY CHARGES

Less than a decade ago it was the recognized custom to employ light charges in the retort, and to work these off in short periods of carbonization. Six hours was looked upon as a convenient period, so that the retort could be filled four times during the twenty-four hours. When such systems are adopted the coal lies in a thin layer upon the floor of the retort, thereby leaving a large crown space unoccupied. By prolonging the period to either eight or twelve hours the labour entailed is curtailed by one-third or a half, and many further advantages accrue. With the six-hour charge the weight of coal distilled in a "through" retort of average cross-section was usually 6 cwts.; and it may be taken as a rough rule that the number of cwts. shall be equivalent to the period of carbonization in hours.

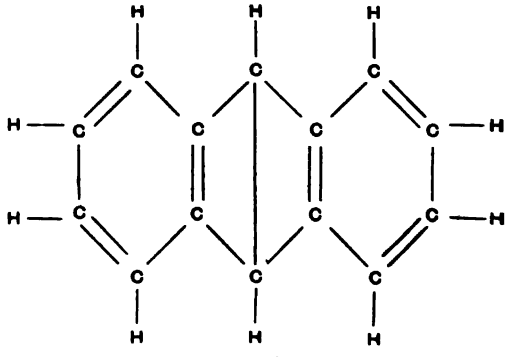
Thus, a 6-hour charge consists of 6 cwts.
an 8-hour ,, ,, ,, 8 ,,
and a 12-hour ,, ,, ,, 12 ,,

In each case it will be seen that the weight of coal employed in twenty-four hours is approximately the same; but whereas in the six-hour charge it has to be handled on four distinct occasions, with the twelve-hour charge only two handlings are necessary. The primary objection to the six-hour charge is, however, the excessive degradation and decomposition which takes place in the greater free space above the coal. Owing to the tendency of the gas to linger in the retort, and to its slow passage there though in contact with incandescent surfaces of carbon, the destructive influences are afforded exceptional facilities for working their evil. It

must be remembered, moreover, that although decomposition by heat occurs in what may seem a minute space of time, in the ordinary way the thermal degradation of the hydrocarbons takes place very slowly in comparison with the rate at which many other chemical reactions occur. Thus an increased time of exposure tells heavily in this direction. As the bulk of gases travel along the free space to the outlet pipe, portions of them will be in contact with the sides of the retort, etc., where their temperature quickly rises to that of the surfaces, and it is here probably that the most intense degradation occurs. The gases towards the middle of the bulk, however, absorb the radiant heat traversing the space, and as the more complex compounds have a greater absorptive capacity than the simpler bodies for radiant heat, the tendency is for the more stable gases, such as methane, to remain unharmed whilst the complex vapours are split up. It is for this reason that the condensible vapours and gaseous hydrocarbons are of a distinctly benzenoid character with light charges. Furthermore, the excessive degradation gives rise to the deposition of free carbon, which, in turn, causes stopped pipes ; and naphthalene makes its appearance in undesirable quantities. The naphthalene formation may be explained by the fact that when subjected to excessive heat benzene probably polymerizes, so that the following compounds containing condensed benzene nuclei are formed :—



Naphthalene



Anthracene

During the formation of such compounds hydrogen is evolved in some quantity, and accounts for the high percentage of this gas usually found in the resultant gas from light charges. With regard to the " free " carbon deposited, it is interesting to note that Colman considers that with still higher temperatures and with increase of time the above compounds yield more hydrogen and benzene nuclei of a still more complex nature, leading eventually to carbon itself. The molecule of solid carbon in all probability consists of a very large number of carbon atoms arranged as a honeycomb of condensed benzene nuclei. These complex substances, still containing some hydrogen, are black and infusible, and their physical properties are very closely akin to those of pure carbon itself.

As regards the extent of free space in the retort with varying types of charges, G. P. Lewis has given the following figures :—

22 inches by 16 inches ⊂ retort, 6 cwt. charge ; space in crown =65 per cent. of volume of retort.
" " " " 8 " " " " =55 " " "
" " " " 12 " " " " =32 " " "
Coke oven 9 feet by 1 foot 6 inches . . . . = 6 " " "

In the Woodall-Duckham vertical retort the free space is variable, at will, and amounts to 0·7 to 1·4 per cent. of the total volume of the retort.

As regards the effect of varying the duration of charge upon the products obtained, Ferguson Bell gives the following comparisons :—

Duration of charge.	Weight of charge.	Gas made per ton.	Candle power No. 2 Met.	Calorific value per cubic foot.
Hours.	Cwt.	Cubic feet.		B.Th.U. Net.
6	6	10,594	16·31	538·8
8	7¾	11,245	15·59	518·9
10	9½	11,499	14·53	488·4
12	11½	11,463	14·77	484·4

The principle of the heavy charge has recently been carried to further lengths by Mr. Isaac Carr, who has installed at Widnes retorts having a cross section of 24 inches by 20 inches, and capable of carbonizing about a ton of coal in twenty-four hours.

To sum up, the merits of the heavy charge as compared with the results from partly filled retorts may be enumerated as follows :—

(1) Considerably curtailed carbonizing costs.
(2) Less degradation, and, therefore, less naphthalene and free carbon.
(3) Few stopped pipes.
(4) More ammonia.
(5) Better coke of a denser nature, and less breeze.
(6) More tar of a better and thinner quality.
(7) Less scurf.
(8) Less sulphur in the form of CS_2, etc.

Some doubt seems to exist as to the question of fuel. Whilst some authorities imply that the heavy charge is more extravagant in this direction, this would by no means appear to be the rule. The " make per mouthpiece " per day shows some falling off, owing to the fact that with the heavy charge the final hours of the period are largely yielding only the residual gases from the coke—comparatively small in volume, and which are not evolved to the same extent in the short carbonization periods. With the heavy charge, it is, of course, essential that the periods of charging of the various units should be so arranged that the resultant mixture of gas obtained is more or less constant throughout the twenty-four hours.

THE TEMPERATURE THROUGHOUT THE CHARGE

The temperatures prevailing throughout the carbonizing mass vary to some extent with the weight of the charge, and it is generally found that whereas with the

light charge the hottest zone is that in contact with the bottom and sides of the retort, with complete filling the hottest portion will be that forming the surface of the coal. The pyrometric observations of Bond, recorded in the proceedings of the Institution of Gas Engineers, are of considerable interest and throw much light on the conditions prevailing. This investigator has shown that the solid residue tends to divide into two distinct layers, and he recorded temperatures at the three zones (*A*, *B* and *C*, Fig. 189) for varying periods of the charge. At the zone *A* the temperature at the commencement of the charge was 1,250° Fahr.; at the end of the first two hours, when 37 per cent. of the total gas had been evolved, it was 1,460° Fahr.; whilst after four and a half hours a maximum of 1,850° was attained. As regards the zone *B*, at the centre of the charge, after the coal had been distilling for two hours the temperature was approximately the same as at the base of the charge, but never exceeded the latter. At the commencement of carbonization the temperature of the core—as would be expected—was only 830° Fahr. These results all refer to a charge 6 inches in depth. Considerable variation was found when the thickness of the coal layer was increased to 12 inches. In this case the temperature of the core at the commencement was no more than 200° Fahr., but as carbonization proceeded a gradual increase was noticeable, until after eight hours there was a temperature difference of only about 50° Fahr. between the base and the core of the charge. At this period the hottest portion of the charge was the surface, which had risen to about 1,950° Fahr.

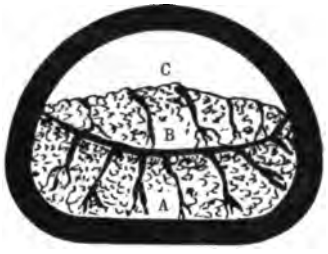


FIG. 189.—TEMPERATURES AT VARIOUS ZONES OF CHARGE.

The following table, compiled from figures given by G. P. Lewis, gives a useful insight into the conditions of temperature obtaining during an eight-hour charge :—

		Time after commencement of charge.								
		Hours.								
		½	1	2	3	4	5	6	7	8
		Degrees Fahrenheit.								
Light charge (6 inches thick)	Bottom	1,290	1,360	1,460	1,700	1,850	1,870	1,870		
	Centre	1,110	1,250		1,650	1,900	1,830	1,830		
	Top	930	1,100	1,360	1,600	1,740	1,760	1,850		
Heavy charge (12 inches thick)	Bottom	1,110	1,170	1,290	1,380	1,440	1,470	1,560	1,690	1,890
	Centre	200	210	300	410	500	610	1,080	1,470	1,870
	Top	1,380	1,470	1,560	1,590	1,620	1,690	1,780	1,870	1,920

With regard to vertical retorts of the continuous type, at the point of combustion

the temperature is about 2,400° Fahr., and at the base of the retort it is approximately 2,000° Fahr. It must not be lost sight of that in the vertical retort progressive heating may be employed, whereas in horizontal systems this is not practicable. By such heating, the prevailing temperatures of the various portions of the retort may be varied and the charge subjected to differing intensities of heating as it travels downwards. Thus we get the two types of heating, namely, top and bottom, in the first of which the upper portions of the retort are subjected to the most severe temperatures (as in the Woodall-Duckham system), the lower portions being more highly heated in other systems, such as the Glover-West and Dessau. The conditions prevailing in vertical retorts are illustrated in Figs. 190 and 191. Whilst in continuous systems the relative positions of uncarbonized coal, the viscid layer surrounding it, and the coke zone remain practically constant, this is not the case with intermittent systems, in which the pasty envelope gradually closes in towards the centre of the charge. With continuous charging, even if top heating be adopted, the upper portions of the mass will still be relatively cool, so that the primary gases coming away at low temperatures are subjected to the minimum of degradation. With intermittent working, however, it is essential to heat the base of the retort more highly, for in this way the lower portions of coal are carbonized in advance of the upper, and thus a freer passage through the central core is assured. The coke, moreover, is subjected to a maximum temperature just before leaving the retort, so that a considerable proportion of the volatile matter is expelled from it. That this is desirable is shown by tests carried out by Davidson, who found that even " well-burned-off " coke will give off quite a large amount of gas. Taking an ordinary coke containing 1·97 per cent. of volatile matter, it was shown that on further heating this would yield an additional quantity of gas equal to 2,900 cubic feet per ton of coke, the composition of the gas being as follows :—

FIG. 190.

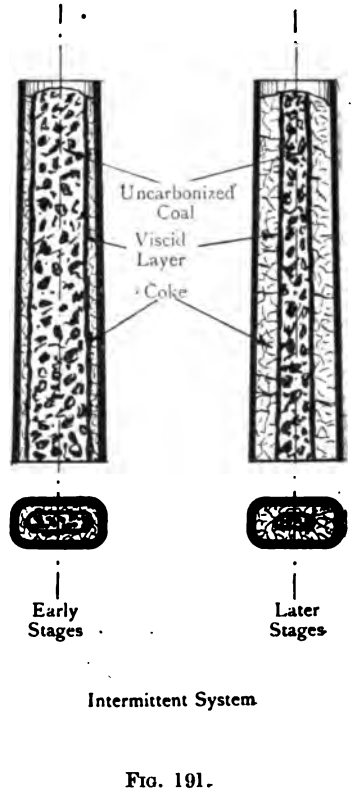


FIG. 191.

Hydrogen	86·8 per cent.
Methane	2·05 „
Carbon monoxide	6·5 „
Carbon dioxide	0·6 „
Nitrogen	4·05 „

Coke from the Dessau retorts rarely contains as much as 1½ per cent. of volatile matter.

THE TRAVEL OF GAS IN VERTICAL RETORTS

So far as the path by which the gas finds its exit from the horizontal retort is concerned, when once a ring of hot coke has been formed around the cool coal core the only way of escape for the products is through this heated zone. In both types of vertical retorts, however, matters are different, and the volatile constituents may leave either by way of the cool central core, or by evolution from the outer layers of the pasty envelope they may travel upward through the heated coke. The former, owing to the absence of excessive degradation, is, of course, the most desirable outlet, and Bueb is of the opinion that with intermittent vertical systems the gas takes this course. Colman, however, who has done much work in connexion with the problem, holds the view that Bueb's hypothesis is only true to a very limited extent, except in cases where no pasty envelope is formed—as with shales and non-caking coals. "Vertical" gas shows none of the characteristics of a low temperature gas, such as would be obtained if the products took the cooler path. In fact, hydrogen is somewhat higher than is the case with "horizontal" gas, ethylene is comparatively low, and ethane—essentially a primary product—is entirely absent. The tar, moreover, inclines towards a benzenoid character. Colman corroborated his views by analysing the gas from various portions of the retort, with the following results :—

	Gas drawn from coal core.	Gas drawn from coke zone.	Final gas obtained.
Hydrogen	45·3 per cent.	59·0 per cent.	53·5 per cent.
Methane	37·2 „	20·2 „	28·0 „
Carbon monoxide	8·8 „	12·9 „	11·9 „
Carbon dioxide	5·9 „	3·0 „	3·2 „
Unsaturated hydrocarbons	2·0 „	1·9 „	2·3 „
Oxygen	nil	nil	nil
Nitrogen	0·6 „	3·2 „	1·3 „

The marked resemblance of the final gas to that obtained from the coke zone will be noticed. Colman concludes his argument by stating that probably, on the whole, the volatile products are subjected to the influence of the heated coke surfaces to a rather greater extent than is the case with horizontal retorts.

Vertical retorts, though having fully established their claims in many directions, are still passing through a stage more or less of evolution, and therefore it is inopportune to discuss their relative merits as carbonizing agents compared with the time-

honoured horizontal retorts. One cannot do better than quote the views of an authority who has had every opportunity of experimenting with all kinds of plant. His opinion is that " on summing up the respective balance-sheets, very little difference may be found between the two competitive systems, and local circumstances may settle the question one way or the other."

" STEAMING " IN VERTICALS

Mention has already been made of the practice of " steaming " as usually adopted in the intermittent forms of vertical retorts. The effect is to swell the gas yield to some extent whilst the deterioration in quality is not marked. Davidson gives the following comparative analyses :—

	Without steaming.	Steam for last 2 hours of 12-hour charge.
Hydrogen	55·2 per cent.	55·6 per cent.
Methane	27·5 „	27·1 „
Carbon monoxie	11·0 „	11·1 „
Carbon dioxide	2·25 „	2·2 „
Unsaturated hydrocarbons	2·63 „	2·58 „
Oxygen	0·43 „	0·43 „
Nitrogen	1·0 „	1·0 „

These figures, for the purpose of comparison, are reduced to 1 per cent. of nitrogen content. The steaming gave an increase of yield of 280 cubic feet of gas per ton, whilst a decrease of 4 B.Th.U. per cubic foot was found.

The figures of Drury, given below, enable a good indication to be obtained of the effect on illuminating power :—

	Gas per ton.	Illuminating power.	Net calorific power.
Charge unsteamed	11,838 cubic feet	16·86 candles	536 B.Th.U.
„ steamed	12,996 „	16·62 „	534 „

Thus an increase in " make " of 1,158 cubic feet is obtained with practically an unnoticeable difference in quality.

CHAPTER XII

THE CONDENSATION OF COAL GAS

ALTHOUGH the operation of condensation might appear to be one of extreme simplicity, this is by no means the case ; for the character of the final products obtained is appreciably influenced by the manner in which the gas is dealt with at this stage. Condensation may be best defined as the reduction of the gas to normal temperatures, and the simultaneous removal of all those substances which are not permanent gases at such temperatures. In the main, the apparatus employed for the purpose is of a simple nature, and merely embodies the principle of exposing large surface areas to the action of a cooling agent. On gasworks the cooling medium employed is either air or water, or both. The atmospheric condenser was a common feature of gasworks in the past, and it is still to be found in many of the smaller and medium-sized works. As a cooling agent, however, water is infinitely more efficient. When a temperature drop of 10° Fahr. is required, the capability of water (per square unit of surface exposed) to bring about the reduction is eleven times as great as that of air, and when the temperature drop increases to 50° Fahr. the proportional efficiency is more than 200 to 1. In addition, the water-cooled condenser is easily regulated, so that a more or less constant outlet temperature may be obtained whether the apparatus is working up to its full capacity or not.

ATMOSPHERIC CONDENSERS.

Condensers of the atmospheric type are of no stereotyped construction, and in the case of some small works are often made up from odd lengths of pipe and connexions which the manager may have at his disposal. In general, however, the chief standard varieties in common use may be classified as follows :—

(*a*) Horizontal types.
(*b*) Vertical types.
(*c*) Annular types.
(*d*) The battery condenser.

The horizontal condenser shown in Fig. 192 frequently takes the form of an extended foul main which is carried in zigzag fashion from end to end of one of the retort-house walls. As blockages from naphthalene or pitchy deposits are likely to occur at times, it is essential that flange connexions should be used, so that clearing may be easily effected. The condensed liquids flow down the sloping pipes in the

same direction as the gas. In the general way this procedure—when slow travel is assured—would seem to be quite effective in the removal of naphthalene. In conjunction with the steel foul main, steel is also being employed to some extent in the construction of condensers. The horizontal condenser shown in the sketch is constructed in spiral form, and differs from the most simple type in that it rests upon its own stanchions. A common type of vertical air condenser complete with gas and tar outlets is shown in Fig. 193. The annular atmospheric condenser (Fig. 194) has in the past assumed a good deal of importance, and is probably the most satisfactory example of these types, in that the intensity of cooling is to some extent under control. As can be seen from the sketch, the gas passage in the tall vertical

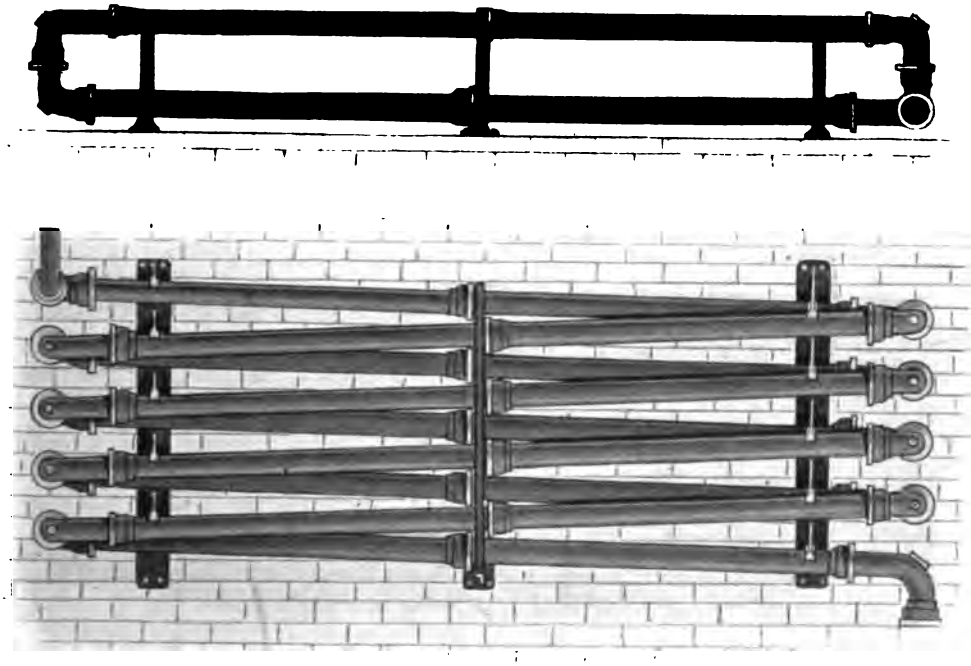


FIG. 192.—HORIZONTAL CONDENSER.

cylinders is annular in form, hence both an inside and outside surface are exposed to the cooling effect of the air. The diagonal side pipes convey the warm gas to the upper ends of each annular cylinder, and in this way a comparatively strong draught is caused to ascend the inner air tube. Butterfly valves or dampers are fitted to the top of each vertical air pipe, so that the amount of cooling can be regulated in accordance with requirements. These valves are usually operated by means of a hand chain reaching to the ground. Occasionally this type of condenser is found with the diagonal pipes omitted, the cylinders being connected by short horizontal branches, in which case the gas travels up and down the cylinders alternately.

The annular condenser shown in the figure is the improved Walker type, and may be composed of any number of tubes. It will be noticed that the inner cylinder is coned, so as to increase the annular space at the bottom. In this way stoppage due to tarry deposits is avoided. The base of the annular space is also given a fall, so that tar may run away readily to the seal-pot.

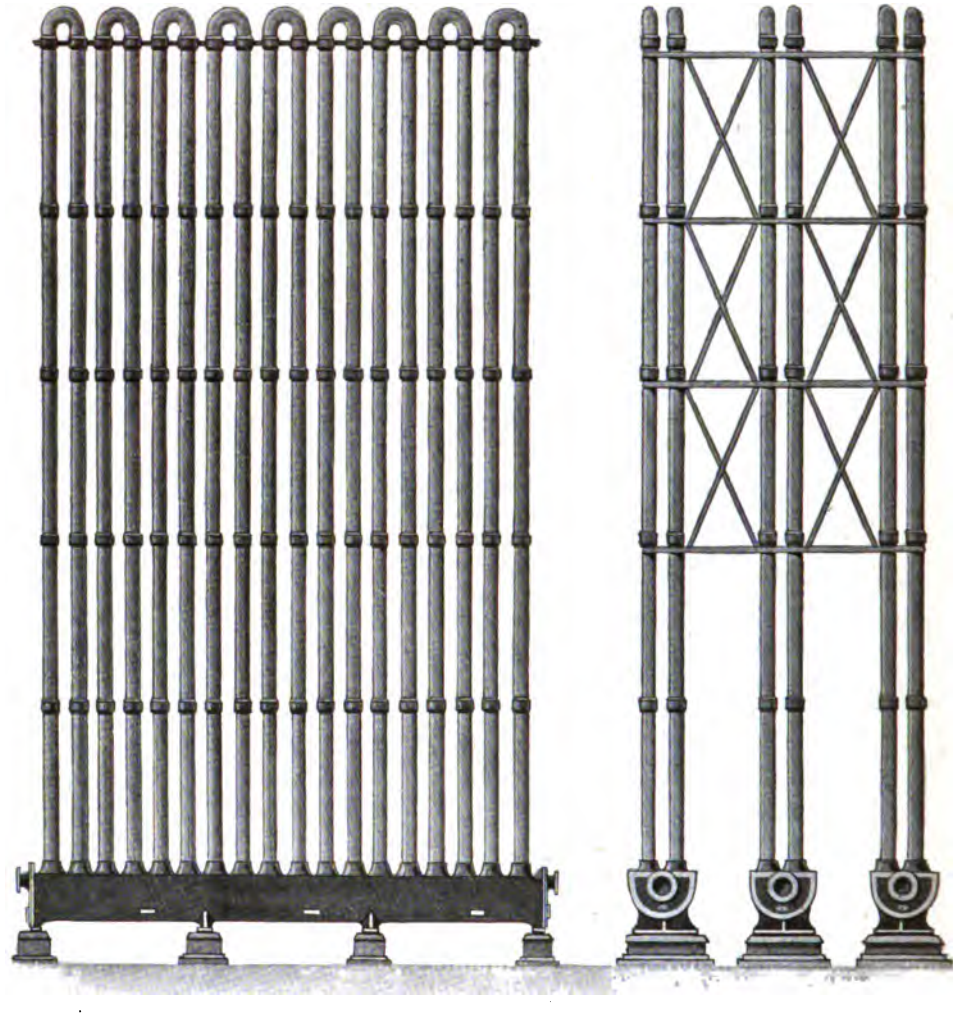


FIG. 193.—VERTICAL CONDENSER.

The battery condenser (Fig. 195) is of somewhat novel construction. It consists of a long and narrow box divided internally by baffle-plates which cause the gas to take a circuitous course. The width of the box is usually about 2 feet, and small tubes passing from side to side form the chief cooling surface. The ends of

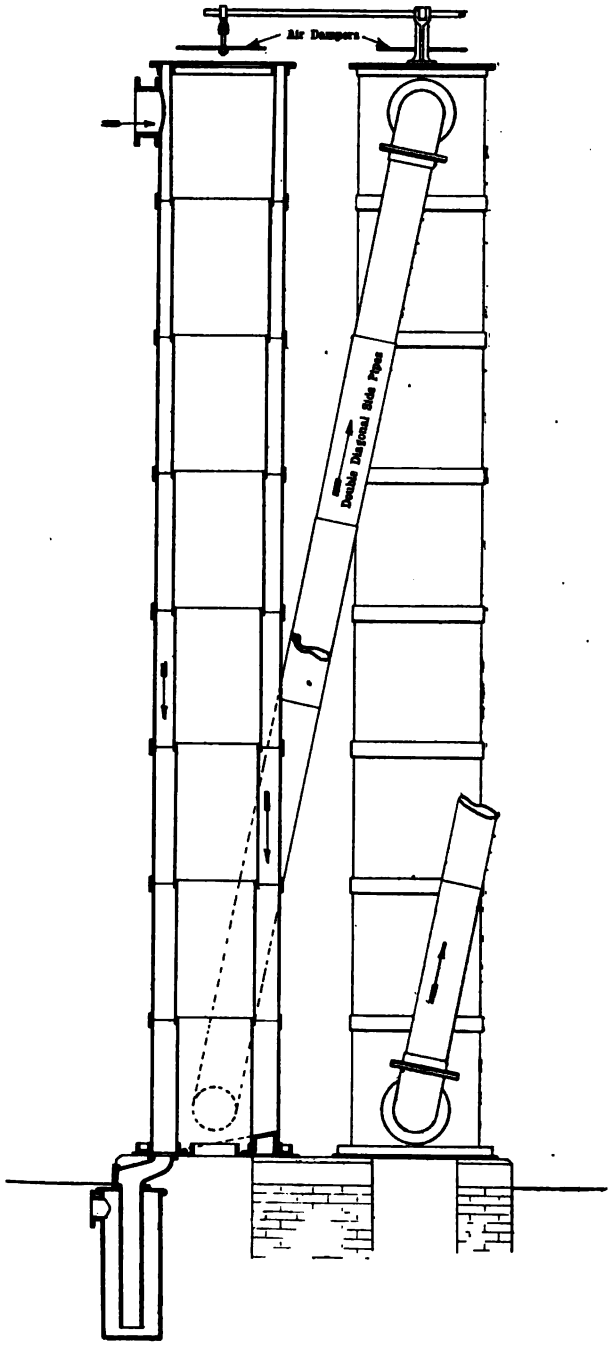


FIG. 194.—ANNULAR CONDENSER.

these tubes are left open, so that a current of air readily passes through. In addition, the obstruction caused by the tubes has some effect in breaking up and throwing down the tarry vesicles suspended in the gas.

So far as capacity of condenser plant is concerned, the most reliable rule from which to form an estimate is that which provides an allowance of 5 square feet of superficial area per 1,000 cubic feet of gas made per diem. This is sufficient (but not extravagantly so) when cast-iron mains and apparatus are employed, and may be slightly reduced when wrought iron or mild steel is used. It must be borne in mind that the figure given by this rule includes (in addition to the areas exposed by the actual condenser) the area of all piping between the outlet of the hydraulic main

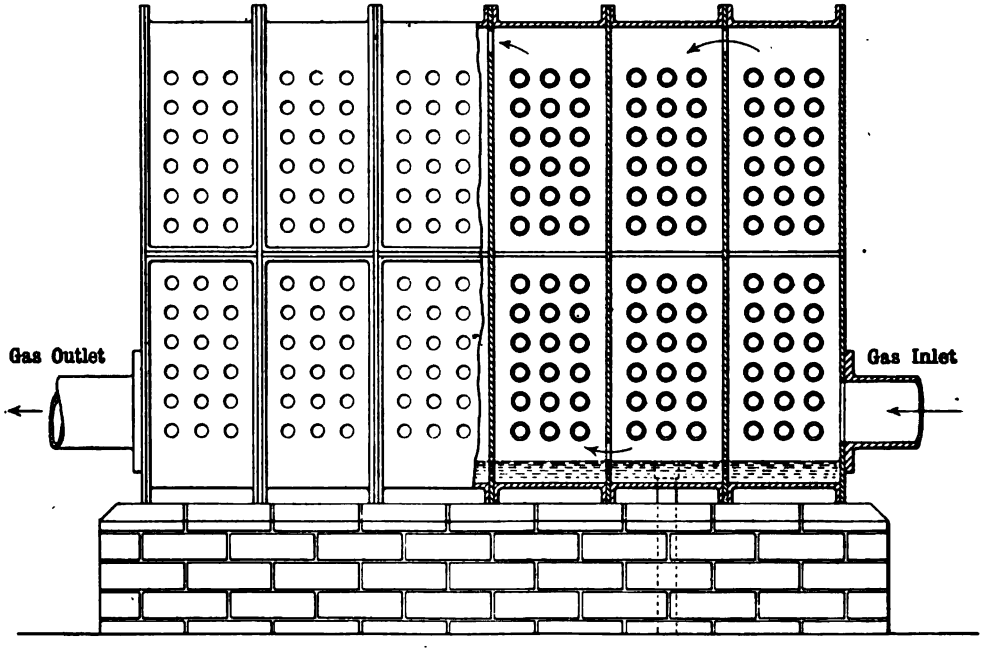


FIG. 195.—BATTERY CONDENSER.

and the inlet of the condenser. This is readily calculated. The following relate to pipes commonly in use as foul mains :—

6-inch	pipe.	Each	foot	run	exposes an area of	1·57 square feet.
9-inch	„	„	„	„	2·35	„
12-inch	„	„	„	„	3·14	„
15-inch	„	„	„	„	3·92	„
18-inch	„	„	„	„	4·71	„
24-inch	„	„	„	„	6·28	„

Many other rules exist for computing the capacity of condensers. One based on the quantity of coal states that 100 to 120 superficial feet should be allowed for every ton carbonized per diem. Another rule, based on thoroughly sound principles, but difficult of application in practice, says that 4 square feet of surface should be

allowed per gallon of water yielded per ton of coal. In order to preclude the too sudden condensation of gas there was in past years a generally recognized formula stipulating that of the total length of foul main 20 feet of length per inch diameter of the pipe should be under cover in the retort house. The rule, however, has lost its significance in present-day practice.

WATER CONDENSERS

Water condensers as now employed are almost solely constructed from riveted mild steel plates (which form the outer shell) and steel or wrought-iron tubes. There are two distinct types at present in use, namely :—

(*a*) Multitubular condensers.
(*b*) Water-tube condensers.

Although both types possess their respective advantages, it is now generally recognized that, except in cases where the condensing water is exceptionally clean, the water-tube condenser is to be preferred. The outstanding distinction between the multitubular and water-tube condenser is that in the former the water passes outside and around the tubes which carry the hot gas, whereas in the latter type

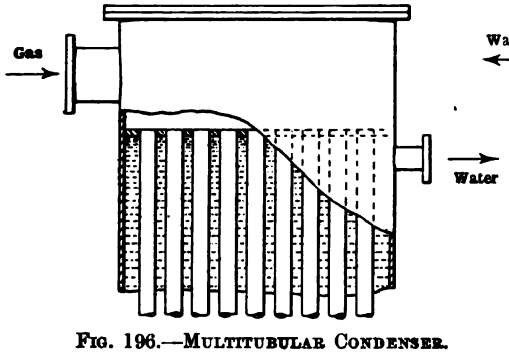


FIG. 196.—MULTITUBULAR CONDENSER.

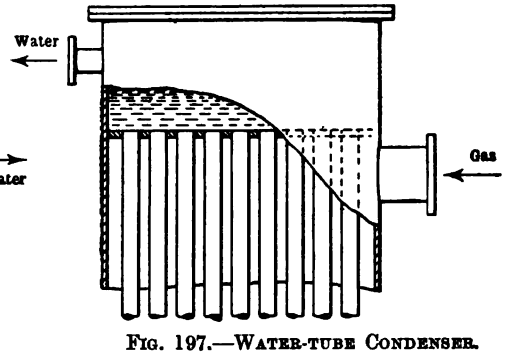


FIG. 197.—WATER-TUBE CONDENSER.

the opposite is the case. The difference is clearly seen by reference to Figs. 196 and 197. It will be realized that when any deposit is likely to take place it is far preferable to have this within the tubes, which can be readily cleaned, rather than in the chamber surrounding them. Thus when only muddy water pumped from rivers or canals is obtainable there should be no hesitation in adopting the water-tube system. On the other hand, if the incoming gas is particularly dirty and contains an undesirable quantity of heavy tar vesicles, the outer chamber is liable to obstruction from this cause. In the calculation of the area of cooling surface required it should be remembered that the actual surface to be considered is that with which the gas is in contact. Hence when the gas travels inside a tube the interior surface must be taken, but when the gas is surrounding the tube the exterior surface is considered. From this it will be seen that the water-tube type gives more condensing area for the same number of tubes. Mention has already been made of the com-

bined atmospheric and water-cooled condenser. This in reality amounts to nothing more or less than a condenser of the water-tube type. In this case it will be seen that the outer casing is available as an atmospheric cooling surface, whereas in the multitubular condenser this function is lost, owing to nearly cold water (instead of hot gas) being in contact with the shell. J. S. Haug has pointed out that the upkeep of the multitubular condenser as regards painting is much more expensive, due to what is commonly called "sweating," which is occasioned by the condensation of moisture from the air on the cold shell. In the case of the water-tube condenser the shell is hot, and condensation, therefore, does not occur in this manner.

So far as the actual condenser capacity required for a given works is concerned, the general allowance for all types of water-cooled apparatus may be taken as 3 square feet of cooling surface per 1,000 cubic feet of gas passing per maximum diem. In the case of the multitubular type of condenser a deduction (calculated on the rule already given for air-cooled apparatus) may be made for the surface of the outside shell, whilst for all types the length of foul main should be considered, as previously pointed out. To determine the efficiency of a condenser and its ability to deal with a given set of conditions it is necessary to consider :—

(*a*) The average inlet temperature and the desired outlet temperature.
(*b*) The condition of saturation of the gas.
(*c*) The rate of transmission of heat from the surfaces employed.

First, it has to be recognized that the aqueous vapour with which the hot gas is saturated accounts for by far the largest share of the total work of condensation. This is due to the fact that the water vapour has to be deprived of considerable quantities of heat, the same applying in some measure to the liquefiable hydrocarbons. A. F. Browne has estimated that of the total work of condensation 87 per cent. is accounted for in removing aqueous vapour, and 13 per cent. in cooling permanent gases and in condensing liquefiable hydrocarbons. Crude gas, although deprived of a large portion of the aqueous vapour it originally contained, is still in a state of saturation when it arrives at the condenser inlet. If this were not the case the process of condensation would be a trifling matter. The actual number of heat units to be extracted can be arrived at by ascertaining the weight of water vapour present in the gas passing at the inlet, and, similarly, the weight of water vapour present at the outlet. The difference will give the weight of water condensed out of the gas. This figure multiplied by the thermal units to be liberated per pound of water between the inlet and outlet temperatures will give the total amount of heat which is to be eliminated. The ability of a surface to transmit heat varies to some extent, not only with the difference between the temperatures involved, but with the condition of the surface, *i.e.*, whether clean or coated. Haug, in careful experiments, found that when the difference in temperature between the two surfaces (*i.e.* the heat potential) was 30° Fahr., the heat transmission amounted to approximately 6 B.Th.U. per square foot of surface under average working conditions. It is pointed out, however, that as temperature differences decrease the unit given will slowly decrease, and *vice versa*.

THE DESIGN OF CONDENSERS

Several types of water-cooled condensers are in use to-day, but in many cases the difference is only a matter of detail. Older patterns having cast-iron shells are still in evidence, but in general the construction will conform to that shown in Fig. 198. This condenser may be used singly or in batteries, and some means should always be provided wherewith the flow of gas and water may be reversed. So far as general dimensions are concerned, the height of the apparatus should be from two to five times the diameter. For smaller condensers 2-inch water tubes may be employed, but the 3-inch is preferable for all larger types. A point to remember is that the length of the tube should not be such as to make it structurally weak; it is as well to confine the ratio of length to diameter within the limit of 80 to 1. The larger tubes are certainly more easily kept free from stoppage and are more readily cleaned, but there is some limit to their size in that as the diameter increases the cooling surface per unit area of ground surface is curtailed. As regards length, it is as well to confine this within the limits of manufacturers' stock sizes, otherwise additional expense will be incurred. The 20-foot tube is, perhaps, most suitable for all the larger condensers. In shape the water condenser is nearly always cylindrical, this section facilitating the building together of the mild steel plates forming the shell. Moreover, the shell of the multitubular type has to withstand the stresses due to water pressure, and the cylindrical shape is better able to do so. Only in the case of the largest condensers is it advisable to work to a rectangular section, and then only in those instances in which the saving of ground space is a consideration. So far as the spacing of tubes is concerned there is no hard and fast rule, but it is as well to remember that the free space in the shell should not be too greatly encumbered; otherwise stoppage will quickly result. A good basis to work upon is that of arranging the tubes so that they occupy about 18 per cent. of the total area of the tube sheet. For water gas this should be increased to 25 per cent.

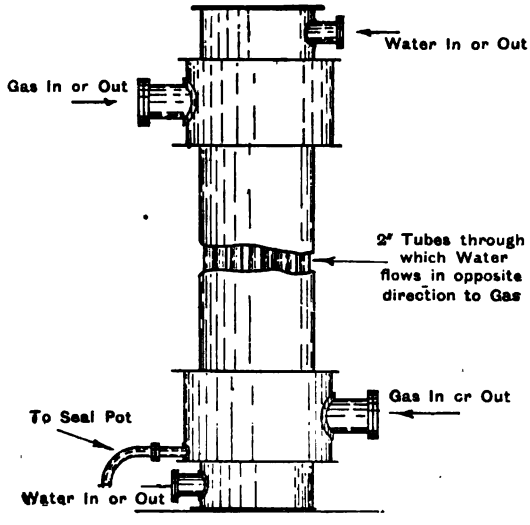

Water In or Out
Gas In or Out
2" Tubes through which Water flows in opposite direction to Gas
Gas In or Out
To Seal Pot
Water In or Out

FIG. 198.—TYPICAL WATER-TUBE CONDENSER.

THE CARPENTER CONDENSER

Dr. Carpenter, in dealing with large units of gas, adopts the hydraulic form of condenser, consisting of a series of vertical cooling tubes placed in a cylindrical vessel

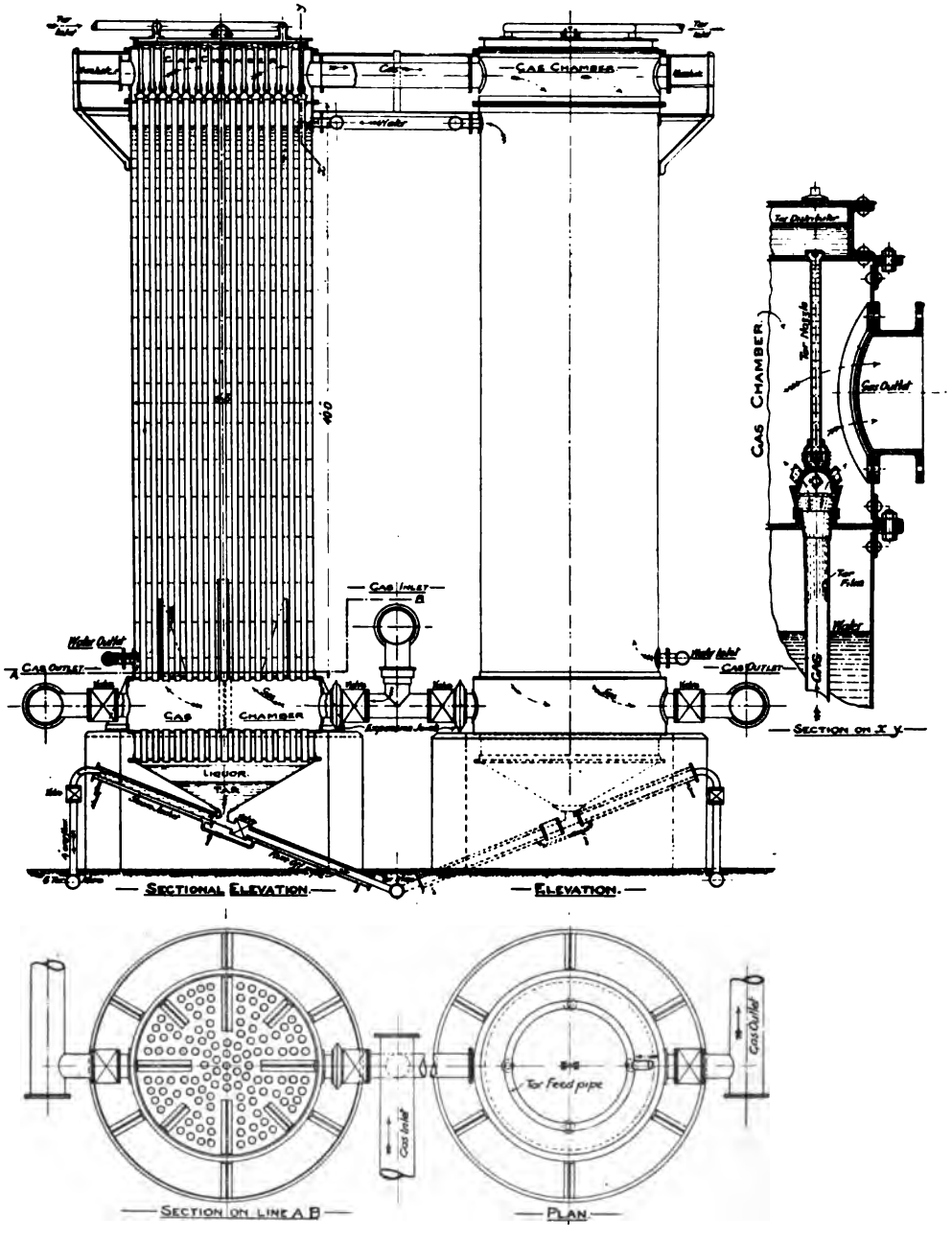


FIG. 199.—CARPENTER'S REVERSIBLE CONDENSER.

containing water. The tops and bottoms of the tubes are connected by gas chambers, and the gas is made to flow upwards through the tubes in one vessel and down-

wards in the second one. The arrangement of connexions and valves is such that the direction of flow of the gas can be reversed when desired. The pair of condensers shown in Fig. 199 are capable of dealing with about four million cubic feet of gas per diem. The cold water enters the condenser near the point of exit of the cooled gas and flows up one vessel and down the other in a direction opposite to that of the gas, the outlet for the water being near the inlet for crude gas. By varying the amount of circulating water a more uniform condensation is obtained under the varying conditions of the atmosphere than is possible in the ordinary air condenser. The tubes are 3 inches diameter inside and 40 feet long, expanded into the top and bottom tube plates.

For the purpose of eliminating a large portion of the naphthalene and for the prevention of deposits in the tubes, tar-spraying devices are fitted on the top of every tube, as shown in the enlarged detail. This consists of a tar-distributing box

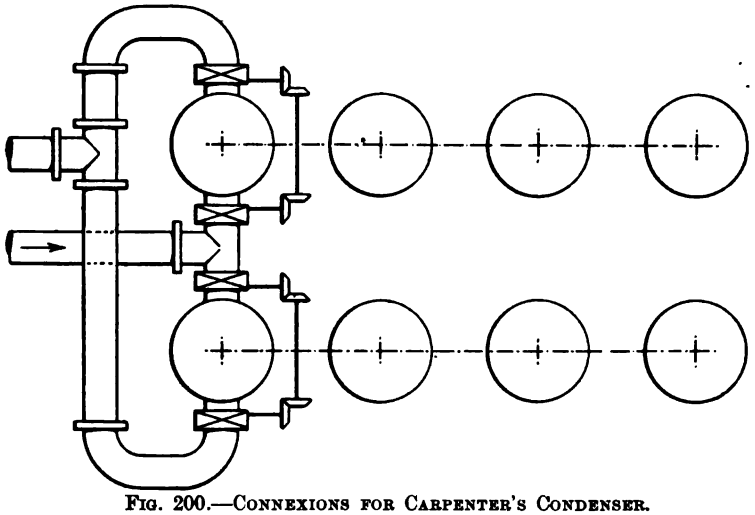


FIG. 200.—CONNEXIONS FOR CARPENTER'S CONDENSER.

at top, with scaled nozzles provided with "spreaders" or crown castings for distributing a thin film of light tar down the inside surfaces of the gas tubes, the tar being pumped into the upper box for this purpose. The gas on ascending or descending slowly through the tubes is washed by this means, and any deposition of naphthalene flows away along with the condensed tar and liquor into a receptacle provided for it in the lower portion of the vessel. A steam-jacketed seal pipe and a run-off pipe are provided as shown. The heated water, after passing through the condensers, is usually circulated through separate air-cooling towers and used continuously over and over again.

The condensers are usually arranged in batteries of any number up to twelve, and are connected up so as to be reversible, as shown in Fig. 200. It will be seen that any possibility of error in operating the valves is guarded against by coupling up the latter by means of gearing. The water valves are arranged in precisely the same manner as those for the gas.

THE THEORY OF CONDENSATION

The primary object of condensation is not merely the cooling of the gas to atmospheric temperature, but to ensure that the bulk of the constituents which are not permanent gases are separated out. By the law of vapour pressures it is known that the saturation content of a gas decreases correspondingly with any reduction of temperature, and that the gas is unable to hold in suspension any excess of vapours above the quantity corresponding with its vapour pressure at the reduced temperature. Accordingly, as the temperature of the hot gas is reduced during its passage through the condenser, a considerable portion of the excess vapours (in the form of steam and liquefiable hydrocarbons) is deposited. As has already been pointed out, it is the aqueous vapour which accounts for the greater portion of the work of cooling entailed.

In the case of coals containing a high proportion of moisture or which yield a large quantity of steam on distillation, the condensation apparatus may be almost entirely occupied in dissipating the heat arising from the formation of steam. Owing to the extremely finely divided condition in which many of the particles are suspended in the gas it is usually impossible to bring about their entire separation by a reduction of vapour pressure by cooling. For this reason the gas is frequently caused to undergo mechanical treatment with a view to removing all traces of solid or liquid matter before its arrival at the wet purification plant. Gradual cooling, with the strict avoidance of " shock," is generally looked upon as the ideal to be secured, for in such cases the hydrocarbons are thrown down in sequence, and there is but slight danger of depriving the gas of a portion of the more valuable constituents which it is capable of retaining at normal temperatures. In connexion with this point Butterfield says that with rapid cooling supersaturation of the gas with certain condensible vapours occurs, whilst other less readily condensible constituents are dissolved or mechanically abstracted by the flushing action of the condensate. He points, moreover, to the probability of the selective action of radiant heat coming into play, and says that radiation from relatively cool walls lowers the temperature of the liquid and solid particles and the more complex gases, whereas more permanent gases are unaffected by it, and are cooled only by contact with cool surfaces.

In considering the principles of condensation, the question of the removal of aqueous vapour may be dismissed, as it is inevitable that the whole of this should be eliminated, with the exception of that portion with which the gas is saturated at normal temperatures. So far as the hydrocarbon condensate is concerned, it is of advantage to sub-divide this in the following manner :—

(*a*) Heavy tars.
(*b*) Medium tars.
(*c*) Light tars and oil fog.

Of the total quantity of tar obtained, about 60 to 65 per cent. will be deposited in the hydraulic main, and this portion is largely of a heavy character. The medium tars, of a somewhat lower specific gravity, are the next constituents to be thrown

down. The greater portion of these will be accounted for during the passage of the products through the main connecting the hydraulic with the condenser, whilst the lighter tars and extremely fine vesicles known as the "oil fog" may travel considerably further. In cases where condensation capacity is insufficient or the apparatus is improperly controlled, considerable quantities of the heavier tar fog will be found to travel forward to the scrubbers, so that eventually stoppage occurs. From the point of view of the retention in the gas of the maximum quantity of the hydrocarbons, the slow travel and gradual temperature drop associated with the horizontal atmospheric condenser cannot be improved upon. In general, the temperature of the gas in the hydraulic main varies between 140° and 160° Fahr. Although this temperature is below the boiling point of the suspended tarry vapours the latter are prevented from depositing owing to their being carried forward mechanically by the moving bulk of gas. The constituents most liable to deposition are benzene, toluene, and, to some extent, xylene, which have an important effect on the ultimate illuminating power of the gas. A well-established rule of condensation states that the minimum temperature to which gas is reduced should not be lower than 50° Fahr. Dr. Carpenter has stated, however, that rapid condensation with a comparatively big temperature drop has been shown in practice to have very little effect on illuminating power. The experiments which this authority conducted were carried out with gas which had been subjected to an extremely sharp drop of from 150° Fahr. to 40° or 50° Fahr.

The whole problem of condensation turns on the point as to the affinity possessed by tar, both in the liquid and "fog" conditions, for absorbing certain low boiling hydrocarbons present in the gas. Gas as it leaves the hydraulic main may be looked upon as being saturated with naphthalene, although with modern systems of carbonization and heavy charges the quantity present has been considerably reduced. There is little doubt that the heavier tars and tar "fog" with which the gas is in contact in the initial lengths of the foul main possess a marked affinity for naphthalene. At the same time prolonged contact must inevitably result in the absorption of valuable low-boiling constituents. Authorities on condensation are, therefore, chiefly in conflict as to whether gas and tar should be separated at the earliest possible moment, or whether prolonged contact between the two should be permitted. As already stated, the heavy tars and high-boiling constituents are mostly separated out in the hydraulic main, although some portion of these is carried still farther forward by mechanical action. There can be little dispute, however, that such tars are detrimental from the point of view of the illuminating power, and should be isolated from the gas with all possible speed. For the same reason a tar seal in the hydraulic main is to be avoided. The solvent action of the heavy tar vesicles becomes more pronounced as the temperature drops. Thus, removal of the heavy fog at an early stage is probably desirable, leaving the lighter qualities to exert their action as a naphthalene solvent.

Colman states that heavy tar fog when allowed to go forward to the condensers affects the removal of the naphthalene solvents in two ways—one favourably and the other adversely. On the one hand, it removes from the gas the vapours of the

light oils, and thus tends to prevent them from reaching the cold end of the condenser, where their action on naphthalene would be most pronounced. On the other hand, such fog as gets forward to the cold end mixes with the light oils which separate there, thus increasing their content of naphthalene and impairing their ability to take up more of this substance. The complete removal of naphthalene can only be affected by the action of solvents which are not already saturated with the product. It would seem, however, that one of the most effective methods of dealing with the crude gas is to eliminate the heavy tars and heavy fog at an early stage, and to ensure the passage of the light oil fog as far forward as the outlet of the condenser. Some form of mechanical action has the most effective results in breaking up and throwing down the heavier vesicles, and Colman has successfully applied the principle of centrifugal force in his "Cyclone" apparatus. This machine, shown in Fig. 201, is usually interposed in the foul main at a point about half-way between the hydraulic main and the condensers. It consists of a wrought or cast-iron cylinder, to the bottom of which is connected an inverted conical chamber, having a seal pipe attached to its lower end. The gas inlet is rectangular and enters the cylinder at a tangent. It contains, moreover, a flap valve by means of which the velocity of the gas is regulated. A whirling motion is thus set up, so that the tarry vesicles are thrown against the sides of the vessel by centrifugal force, broken up, and run off to the seal. The gas, meanwhile, finds its outlet by way of the central vertical pipe. In one instance it was found that in passing through the separator the gas gave up about 3⅓ gallons of liquid per 10,000 cubic feet, of which 60 per cent. was tar and 40 per cent. liquor. This indicates that the amount of tar fog present was 2 gallons per 10,000 cubic feet. It resembled a thin liquid oil tar of the nature of that produced in the manufacture of water gas. The extractor is made in sizes varying from 3 feet to 10 feet in diameter.

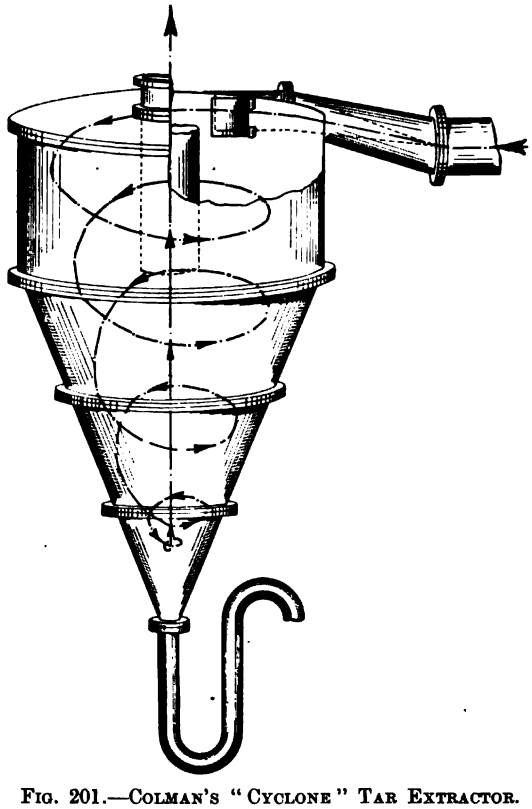


FIG. 201.—COLMAN'S "CYCLONE" TAR EXTRACTOR.

The advocates of the retention of the heavy tars in contact with the gas point out that as the temperature falls the disposition of the tar to absorb naphthalene

increases, hence contact at the lower temperatures is desirable. At the same time it must be remembered that there is a corresponding increase in the capacity of the tar for absorbing the low-boiling constituents. In some cases the " counter-current " principle has been introduced ; that is to say, the tar thrown down in the condensers is run backwards towards the hydraulic main, so that gas and tar are travelling one against the other. In Dr. Carpenter's system tar is sprayed down the individual condenser tubes ; in addition, more or less abrupt condensation is arranged for, so that the naphthalene is eliminated and washed out of the apparatus by the tar.

At Brunswick gasworks a regular system of tar washing has been instituted for the purpose of removing, not only naphthalene, but a portion of the sulphur compounds as well. Tar from an overhead tank, after undergoing filtration, is made to fall in fine streams down the annular space of the condenser limbs. The cold inflowing tar chills the gas, forming a fog, which is removed by the descending stream together with almost all the naphthalene, the greater part of the CS_2, and a part of the H_2S. The approximate quantity of tar used is 3¼ gallons per minute, which reduces the temperature of 3,500 cubic feet of gas from 122° Fahr. to 86° Fahr. It is stated, moreover, that the illuminating and calorific values of the gas are only affected favourably by the treatment.

Whatever methods may be employed in the condensation of coal gas, it must be remembered that illuminating power has in the present day lost much of its former significance ; hence the retention in the gas of the maximum quantity of low-boiling constituents is not so imperative. The greater the proportion of these hydrocarbons retained in the gas, however, the greater will be the latitude afforded for attaining high gas makes ; and from the point of view of economics the valuable constituents should be retained in the gas, and any surplus spread over a greater volume.

THE EXTRACTION OF TAR

On coke-oven works it is customary in some cases to wash the gas for the removal of the suspended tar. In the Otto-Hilgenstock system the vesicles are actually thrown down by spraying the gas coming from the foul main with more tar, as shown in Fig. 202. In spite of the many mechanical appliances now to be had, the complete removal of all traces of tar from coal gas is rarely effected before the

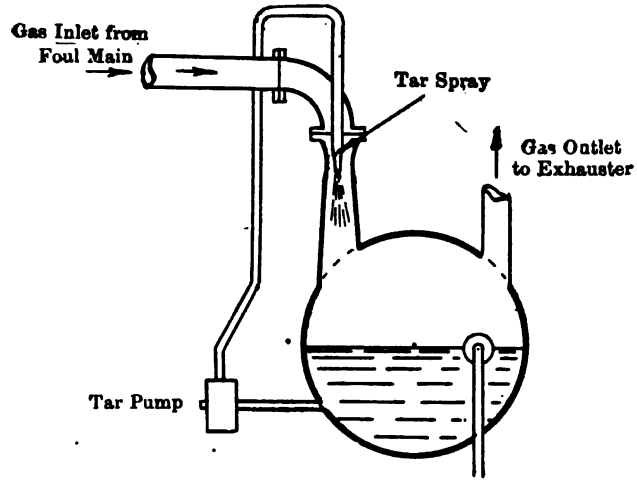


FIG. 202.—TAR SPRAY.

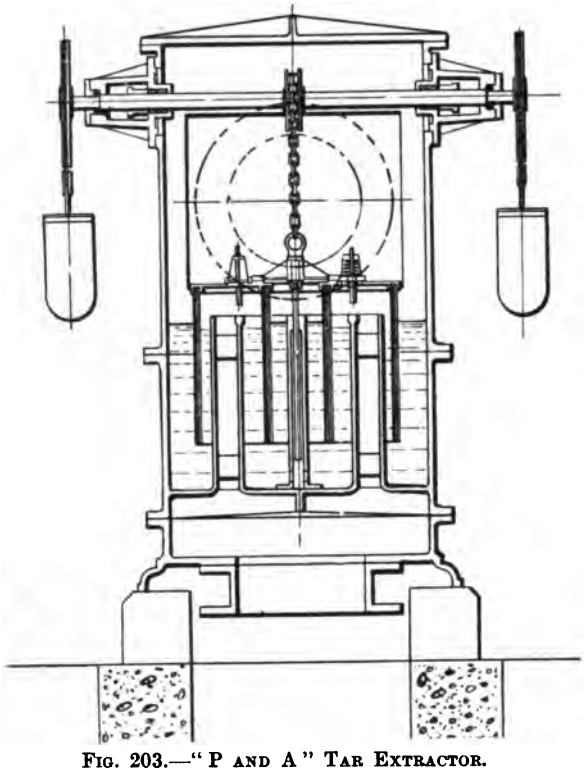


FIG. 203.—"P AND A" TAR EXTRACTOR.

wet purification plant is reached, and the most successful means for attaining this end would still seem to be that of bubbling the cooled gas through a bath of liquid, rather than by the introduction of apparatus embodying the principle of "wire-drawing" or friction. Of the tar extractors operating on the latter principle, the Pelouze and Audouin is probably the most generally utilized. The machine consists of an outer cylindrical casing with the gas inlet entering through the centre of the base. A bell, suspended from an overhead pulley (or in later designs from a central shaft, as shown in Fig. 203) passes over the inlet pipe and has its base sealed in liquor. The weight of the bell is counterbalanced by loading the wheels on the shaft, as shown. This floating bell is composed of a cast-iron polygonal top, having cast-steel posts depending from each corner. The spaces between the posts are filled in with bundles of perforated and slotted plates spaced a short distance apart, the perforations being so arranged as thoroughly to baffle and break up the gas on its outward passage. Safety valves are fitted on the drum top so that in the event of the suspension chain breaking a gas outlet will be provided. The action of the machine is automatic, in that the extractor surface exposed to the gas varies in accordance with the quantity of gas passing through the mains.

A novel method, embodying the use of electricity, has been recently experimented with in America, and has shown itself to be perfectly effective when operated on a fairly large practical scale. The principle introduced has been borrowed from methods employed in connexion with smelter furnaces, where it has been customary to bring about precipitation of solid suspended particles escaping with the gases by means of a direct current high-tension electrical discharge. The investigators have shown that under certain conditions it is possible to throw down the suspended tarry vesicles in crude coal gas under identical conditions. The apparatus employed consists essentially of specially constructed electrodes suspended within a gas-tight chamber (Fig. 204). The chamber is composed of a cast-iron inverted U-tube,

constructed from 8-inch pipe covered on the outside with a jacketing of felt. Each of the arms of the U-tube is 9 feet long, and these form precipitating chambers. An electrode is suspended from the apex of each arm, and is made up from two cast-iron discs connected together by a light piece of gas pipe, while extremely fine discharge wires are afterwards stretched from disc to disc. The discs are 4 inches in diameter, and each electrode—of the squirrel-cage pattern—has an effective length of 5 feet 8 inches. So far as contact time is concerned, it is estimated that the speed of the gas passing through the electrode chambers is about 30 feet per second, and the experiments have shown that the time of exposure to the electrical discharge, which is under half a second, is ample for the removal of the last visible traces of tar. In the latest type of apparatus the difference of potential between the wires and the grounded pipe is kept at 20,000 volts. Incidentally, it has been found that in addition to bringing down the whole of the tar this electrical purifier has certain desirable effects in the direction of minimizing the trouble arising from the deposition of naphthalene. For tar removal the apparatus has been interposed at a point where the temperature is in the neighbourhood of 175° Fahr.—that is, at a very early period in the foul main. Where naphthalene exists in the crystalline state the solid particles may be expelled in the same manner as the vesicles of tar. For naphthalene removal, however, a second electrode is placed at a point where the temperature is at its lowest.

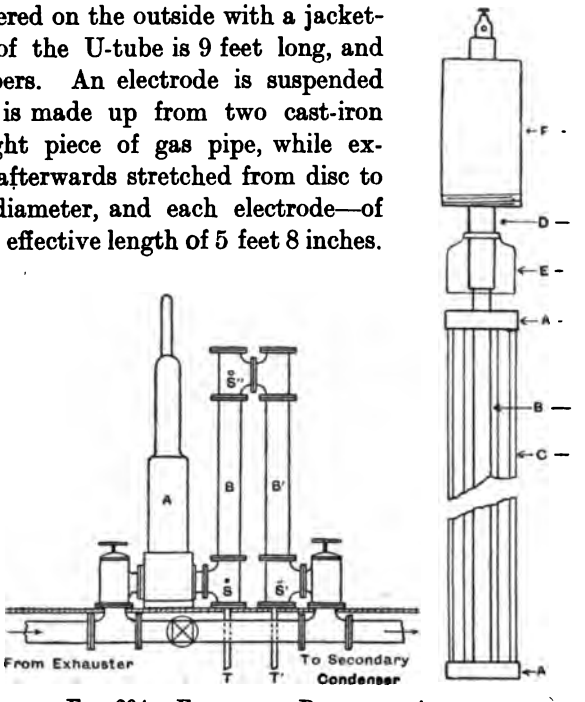


FIG. 204.—ELECTRICAL DISCHARGE APPARATUS.

TREATMENT OF THE GAS FOR THE REMOVAL OF NAPHTHALENE

To the majority of engineers the naphthalene question is still one of extreme importance, chiefly owing to the fact that no definite solution has been reached. Modern methods of carbonization have certainly tended to lessen the trouble caused by naphthalene, but the whole problem stands on unsatisfactory ground—so much so that a method which is effective at one works may be absolutely useless at another. In recent years, however, it has become usual to employ special solvents, to the action of which the gas is subjected before travelling to the district mains. Paraffin, anthracene oil, and water-gas tar are the most common washing agents made use of; but in all cases some reduction in illuminating power will be noticeable until the medium employed has become saturated with the low-boiling hydrocarbons (*i.e.*

benzene, toluene, and, to some extent, xylene), which it removes from the gas. In cases where this temporary deprivation of candle-power might give rise to inconvenience it is advisable to pre-benzolize the washing medium by adding about 5 per cent. of benzol to it. Works manufacturing carburetted water gas will find the tar from this plant the most economical solvent to employ, although the final traces of naphthalene are seldom removed by it. The gas may be washed in the crude or purified state, or either hot or cold ; and where a horizontal washer scrubber is in use it may be so arranged that a few of the bays contain water-gas tar, whilst the remainder are operated with water in the usual manner. Another means is to set aside one of the scrubbers for naphthalene removal purposes, and to circulate water gas through the tiers of coke or boards until the tar has become fully saturated with the hydrocarbon. Extensive contact of this kind is certainly effective from the naphthalene standpoint, but some material reduction in the illuminating power must be expected when a fresh bulk of tar is put into circulation. Probably the most desirable treatment is that of washing with anthracene oil just prior to the gas entering the holder.

The amount of naphthalene in coal gas varies considerably, in accordance with the coals made use of and the system of carbonization employed. The following, however, may be taken as exemplifying the average quantities at the various stages of manufacture :—

Inlet of condensers	80 grains per 100 cubic feet.
Outlet „	20–25 „ „ „
Outlet of purifiers	10–15 „ „ „

By the time the gas leaves for the district the amount will probably be reduced to from 6 to 8 grains, unless some means of removing it is employed. Butterfield has compiled the following interesting table, which shows the amount of naphthalene in gas saturated with the substance at various temperatures :—

Temperature.	Per cent. of naphthalene by volume.	Pounds of naphthalene contained in 1,000,000 cubic feet of gas.
120° Fahr.	0·1070	325·0
70° „	0·0070	23·5
60° „	0·0047	16·0
40° „	0·0028	9·5
32° „	0·0008	2·8

It is pointed out, moreover, that the above figures indicate that, apart from supersaturation effects, a million cubic feet of gas cooled from 68° Fahr. to 50° Fahr. may deposit in the works mains about 14 lb. of naphthalene. When it is remembered that 10 grains of naphthalene will completely block a ½-inch pipe for a length of about 1 foot, the effect of this bulk of naphthalene will be realized.

The methods which have been introduced for the reduction or entire elimination of naphthalene may be summarized as follows :—

(*a*) By employing condensed tars and tar or oil " fog " to its best advantage.

(*b*) By " shock," *i.e.* abrupt cooling.

(*c*) By carburation, or spraying special solvents into the mains.

(*d*) By washing with special solvents.

(*e*) By desiccating the gas.

(*f*) By causing deposition with the aid of electrical discharge (*see* page 301).

With regard to method (*e*), one of the early investigators, Bremond, found that naphthalene is set free wherever there is condensation of the aqueous vapour in the gas, that its deposition is preceded by the deposition of water, and that gas deprived as far as possible of aqueous vapour does not deposit naphthalene. Bremond, therefore, dried his gas by passing it through a vessel containing a desiccating material. A good deal of success attended this method, but the experiments were carried out on only a comparatively small scale. At the present time the water in station meters and gas-holders is often covered with a film of oil so as to prevent further saturation of the gas. Condensation in the mains (probably attended by the deposition of naphthalene) is thus curtailed. Carburation with solvents (method *c*) was introduced by Botley, who injected, by means of a special spray, about 4 gallons of thoroughly atomized paraffin oil per million cubic feet of gas. This investigator found that the oils most suited for enriching purposes are not the best for naphthalene washing ; thus petroleum is more efficient than a light spirit or benzol. When the system is in use, a dark green oil is pumped from the street syphons, this being recovered and made use of on the works for lubrication, or, in some cases, recarburetting. The recovered portion amounts to about 25 per cent. of the original quantity used. The temperature at which the oil mist is injected is of some importance, a degree or two above that of the gas in the mains being most satisfactory. Colson adopted the practice of washing the gas in a Livesey washer (*see* page 334) with an oil specially prepared from tar. The distillate used had an average specific gravity of 0·996 and was obtained at temperatures between 340° and 420° Fahr., being of the nature of creosote. It was not necessary to fill the washer completely with the solvent, and a depth of a few inches on the surface of the liquor was found to be sufficient. Creosote oil of a heavy nature is now largely used for " stripping " the benzene from the gas produced on coke-oven works. Some caution is therefore necessary in its employment for washing purposes on gasworks, for it is quite possible to reduce the illuminating power to 7 or 8 candles in this way. Leather made use of this oil for eliminating naphthalene, but took the precaution to pre-benzolize it first. Once saturated with naphthalene the oil may be distilled, when the benzene and toluene are recovered with the light oils. The naphthalene is then eliminated by means of live steam, and the residue remixed with the benzene distillate and returned to the washer. R. de la Boulaye experimented with a number of substances, ranging from methyl and ethyl alcohol to heavy oils, in order to determine their relative merits as solvents for naphthalene. Finally he concluded that the best remedy for naphthalene was abrupt condensation,

and the ultimate use of a benzol or heavy oil spray in the mains before the gas left for the district. The practice adopted by Ferguson Bell is somewhat uncommon. The gas whilst in a warm state is washed with warm tar; and, at the outlet of the washers and scrubbers, further treatment with a naphtha oil is accorded it.

The introduction of carburetted water gas has undoubtedly gone some considerable way towards lessening the naphthalene evil, although opinions differ considerably as to its utility in this direction. A great deal, however, depends upon the method of manufacture of the water gas, and more particularly upon the temperature to which it is subjected during its passage through the superheater. If the superheater is maintained at temperatures much above the normal the gas will be largely deprived of its solvent properties, owing to the over-cracking of the oils upon which these properties depend.

CHAPTER XIII

EXHAUSTING MACHINERY

ALTHOUGH the exhauster has only come into general use during comparatively recent years its invention extends back to quite the early days of gaslighting, the scientific apparatus employed to-day having been gradually evolved from an exceedingly crude beginning. The necessity for some such apparatus first became apparent when the original cast-iron retorts began to give way to those made from more porous substances. The idea of drawing off the gas from the retorts by the creation of a vacuum seems to have first occurred to an engineer named Grafton, about the year 1839. The machine which this investigator made use of was extremely inefficient, consisting of an ordinary wet gas meter with the inlet and outlet reversed and having the drum driven by power. The notion, however, paved the way for more suitable apparatus, with the result that ten years later the exhauster had become a familiar feature of the larger works. Nowadays, this machine, in various forms, is to be found on all gasworks with the exception of the very smallest, where the cost of installing and operating it would not be commensurate with the saving entailed by its introduction. Where the limit, so far as the size of the works is concerned, should be placed is a matter for argument. It is frequently stated that any works making two million cubic feet of gas or over per annum can profitably instal exhausting plant. When faced with actual facts, however, such a proposition does not bear examination, and, unless exceptional circumstances intervene, the use of the exhauster on works making less than four or five million cubic feet per annum is not to be recommended.

Consideration of an actual case is sufficient to emphasize this point. For instance, consider a works making five million cubic feet per annum. When working without an exhauster the gas made per ton of coal would probably average 9,500 cubic feet, whilst the introduction of the exhauster might account for an increased yield of from 800 to 1,000 cubic feet. In consequence, the coal consumed annually would be reduced from 525 to 480 tons, *i.e.* a saving of 45 tons.

Capital Outlay:—	£	*s.*	*d.*
Engine, exhauster, valves, foundation	80	0	0

N.B.—If no building is available for this plant, an additional outlay (say £30) would be entailed.

Charges to be met (annual):—	£	s.	d.
Interest, depreciation, repairs, and renewals, 14 per cent. on £80	11	4	0
Gas consumed by engine, say 3,000 cubic feet per week at 2*s.*, cost into holder	15	12	0
Oil, stores, etc., per week 1*s.* 6*d.*	3	18	0
	£30	14	0

Resultant Saving:—	£	s.	d.
45 tons of coal at net cost price (after allowing for residuals) of 12*s.* 6*d.*	28	3	0
Wear and tear on carbonizing plant, owing to reduced quantity of coal used, at 1*s.* 6*d.* per ton	3	7	0
	£31	10	0

The balance, it will be noticed, is extremely small, although a good deal will depend upon the distance of the works from a point of delivery for materials, and consequently the price at which coal can be obtained at works. No saving of labour can be contemplated, for on works of such a size a single man only is employed for carbonization. Moreover, the question of labour may operate against the employment of the exhauster, owing to the necessity for the man in charge having some knowledge of mechanical plant. On the other hand, the exhauster offers undoubted advantages in such directions as the control of illuminating power, the reduction of scurf, etc.

Exhausters now employed on gasworks are almost universally of the rotary type, although those operating on the reciprocating principle and designed on the lines of an ordinary steam pump were in common use in days when the rotary machine had not been brought to its present stage of perfection. Primarily, the function of the exhauster, in whatever form it may be used, is that of withdrawing the gas from the retorts by the creation of a vacuum, to avoid the formation of an excessive pressure therein, and eventually to propel the gas through the remainder of the apparatus and into the holders, thus causing the latter to rise. So far as the conditions of the operation of the exhauster are concerned the vacuum induced on the inlet must be sufficient—

(*a*) To overcome the seal on the dip-pipe.

(*b*) To overcome frictional losses arising from the passage of the gas along the foul main.

(*c*) To overcome the resistance offered to the gas by the condenser.

In normal working and when dry mains are not in use, the hydraulic seal amounts to about half an inch, whilst the frictional losses in the foul main may be equal to 1 inch of water pressure, and the resistance of the condensers to 2 inches. Accordingly, it is usual to maintain an average vacuum of about 4 inches of water at the exhauster inlet. On the outlet, the pressure to be overcome varies in accordance with the resistance offered by the apparatus following and the quantity of gas passing at the time. In the aggregate, it may vary between 8 inches to 10 inches on a small country works to as much as 50 inches of water on the largest plants, but in average cases it will be accounted for somewhat as follows:—

PRESSURE CONDITIONS THROUGHOUT THE APPARATUS

Retorts	Level-gauge.							
Hydraulic main	½ inch to 1 inch vacuum.							
Exhauster inlet	4 inches vacuum.							
„ outlet	30 „ pressure.							
Tar extractor, outlet	26 „	„	Pressure thrown by tar extractor,				4	inches.
Washers, outlet	24 „	„	„	„	„	washers	2	„
Scrubbers, outlet	22 „	„	„	„	„	scrubbers	2	„
Purifiers, outlet	9 „	„	„	„	„	purifiers	13	„
Station meter, outlet	8·5 „	„	„	„	„	meter	0·5	„
Holder, inlet and outlet	8·5 „	„	„	„	„	holder	8·5	„
							30	inches

From the above it will be seen that the forcing of the gas through the dry purification material and the raising of the holder bell account for the greatest portion of the work which the exhauster has to perform against back-pressure. At times the physical condition of the purifying material may give rise to considerably increased pressure, when the offending vessel must be shut off, or a tier of oxide "slipped" by drawing the slides specially provided for this purpose.

TYPES OF EXHAUSTERS

In considering the mechanical details of exhausters it is advisable to classify the various types under the following headings:—

(*a*) Reciprocating types.
(*b*) Rotary types.
(*c*) Steam jet types.
(*d*) Turbo-exhausters.

Reciprocating machines operated on the pump principle need be given no further notice owing to their tendency to disappear entirely. Rotary exhausters of various types are almost exclusively used at the present day, whilst the most recent development of the same principle is the turbo-exhauster. The first attempt to construct a practicable rotary exhauster was made by Beale in 1850, and this machine, with important modifications and refinements, has served as a model for the modern apparatus. About the same year G. Jones introduced a blower operating on the Roots' principle, but for gasworks purposes the machine has not gained much favour in this country, although in America it seems to be preferred. Some years later the Beale exhauster was much improved by Messrs. Gwynne & Co., who introduced two overlapping blades instead of the single one originally employed. The Gwynne-Beale exhauster is shown in Fig. 205. The blades pass through slots cut in the inner drum, which is revolved from the source of power. The extremities of the blades are provided with steel cased pins which are fitted into segments. The segments travel in grooves cast in the end covers of the drum, so that when the inner drum revolves the blades are drawn in and out, thus sucking in the gas from one port and discharging at the second. The main defect of this

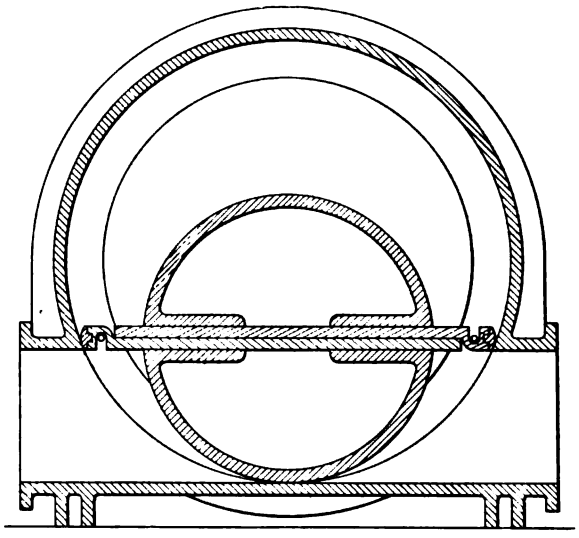


FIG. 205.—GWYNNE-BEALE EXHAUSTER.

exhauster was the large amount of friction produced by the guiding segments running at a high speed, whilst the compound slide required frequent renewal. The machine was, therefore, soon displaced by an improved form, also due to Beale, in which the guiding segments were eliminated. The blades in the new type (Fig. 206) were guided from the centre of the outer casing by the use of a block running on a central shaft fixed in one of the end plates. The two slides were then cast in one piece, and the frictional losses so reduced as to lessen the driving power required to about two-thirds of that of the original machine. A feature in the machine is that the outer casing is not bored to a true cylinder, but is oval in shape, this being necessary owing to the slightly eccentric movement of the blades which slide on the centre block.

MULTIPLE BLADE EXHAUSTERS

The primary objection to exhausters of the two-blade type is the irregularity of the vacuum they produce on the inlet side, particularly when running at slower speeds. In order to avoid such oscillation the exhauster having more than two blades was introduced about the year 1879; and owing to the many advantages

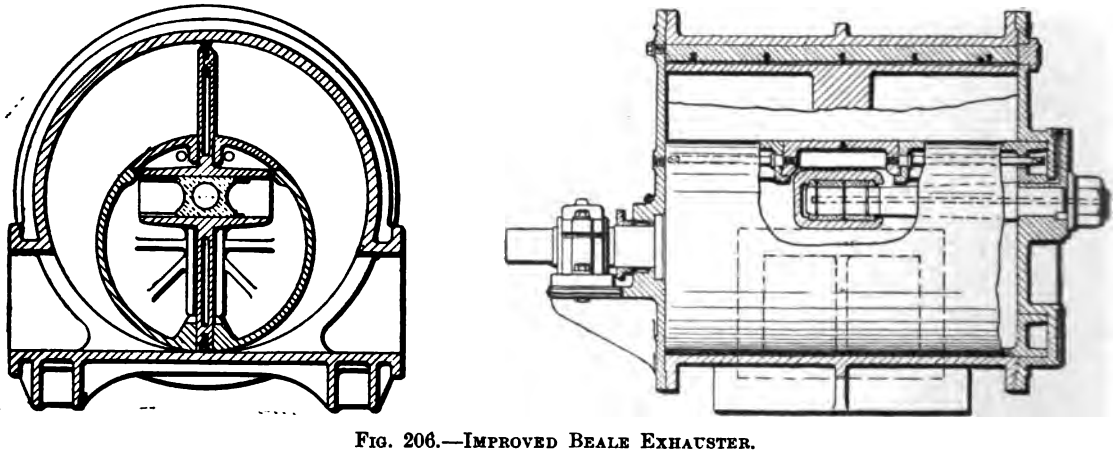


FIG. 206.—IMPROVED BEALE EXHAUSTER.

offered the multiple type is by far the most common in use at the present time. Stated briefly, the advantages which the multiple machine possesses over the two-blade type are as follows :—

(*a*) For the same size an increased capacity is obtained, amounting to about 30 per cent. with the three-blade type and 40 per cent. with the four-blade type, as compared with the two-blade machine.

(*b*) The oscillation is considerably reduced.

(*c*) The outer cylinder is a true circle, consequently no special boring machinery is required.

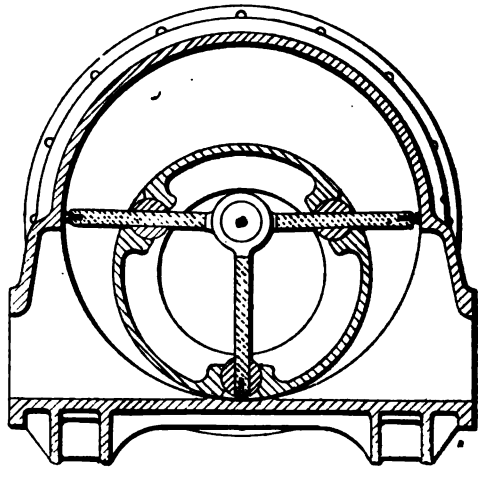


FIG. 207.—3-BLADE EXHAUSTER.

(*d*) The whole machine is more easily constructed.

On the other hand, as is often pointed out, the increase in the number of blades is obtained only by reducing the extent of the wearing surfaces, and some engineers state that the three or four-blade machines have their disadvantages in cases where the back-pressure at the outlet is considerable and where high speed is necessary.

Typical examples of the multiple exhauster are shown in Figs. 207 and 208. The outer drum is bored truly cylindrical, whilst the internal drum (which is about two-thirds the diameter of the external casing) is fitted with three or four small rolls which are slotted out to take the blades, and oscillate in the bearings according to the movement of the blades. The ends of the rolls project beyond the width of the inner drum and are supported in bored recesses in the end covers. The blades are hinged on a shaft which is central with the outer drum, and which extends the whole length of the cylinder and is supported in a deep boss on the back cover, and secured by a nut. To facilitate lubrication this spindle is bored down its entire length. The driving shaft is cast on to the inner drum and projects through a gland and stuffing box in the inner cover. In order to reduce the losses by "slip" the tips of the blades are fitted with T-shaped strips which are forced against the inner

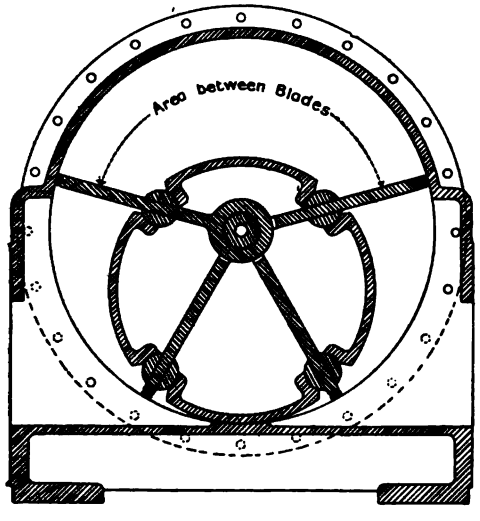


FIG. 208.—WALLER 4-BLADE EXHAUSTER.

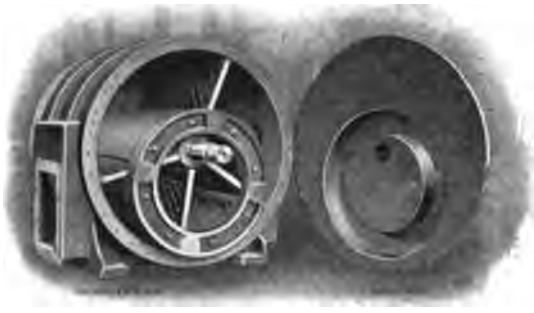


FIG. 209.—WALLER EXHAUSTER WITH END-PLATE REMOVED.

periphery of the drum by spiral springs. The construction of these exhausters will be readily seen by referring to Figs. 209 and 210.

The number of blades fitted bears some relation to the capacity of the exhauster; and, in general, all machines dealing with less than 5,000 cubic feet per hour are fitted with two blades; all above this capacity and up to 25,000 cubic feet per hour are of the three-blade type; whilst four blades are fitted for sizes larger than this. The smallest rotary exhausters made are 3 inches internal diameter and 3 inches long, but these are seldom used for anything beyond adding air to the dry purifiers or for compressing purposes. They are of the two-blade type, running at about 500 revolutions per minute, and having a gross output of about 115 cubic feet per hour. The largest exhausters manufactured, which are chiefly employed on coke-oven works, have a capacity of about 450,000 cubic feet per hour, and are 4 feet 6 inches in diameter. They are almost invariably driven by electricity, as shown in Fig. 211.

METHODS OF DRIVING

Some years ago it was the common practice to drive the larger exhausters by means of belting, but the method is now fast giving way to the direct-coupled system. The belt drive is objectionable owing to the possibility of the belt slipping, in which case the exhauster may stop abruptly, on account of friction between the blades and the case. The cost of driving power is, of course, the chief consideration in the case of the small works, and as steam power is frequently not available in such cases, a gas engine drive through a countershaft and belting is the only alternative. An advantage attending this method is the possibility of driving liquor and other pumps from the same countershaft. (A recommendation for the use of the exhauster in small works—and one which can scarcely be gauged in

FIG. 210.—EXHAUSTER, SHOWING INNER DRUM PULLED AWAY FROM BLADES.

terms of £ *s. d.*—is that a greater pressure may be maintained on the district mains, thus the annual quantity of gas consumed may undergo augmentation.)

On the larger and medium-sized works, where an ample supply of steam is always at hand, exhausters are frequently driven by reciprocating or turbine steam engines. Many devices have been introduced with the object of ensuring efficiency and economy. With the larger exhausters it is always profitable to instal a compound engine, owing to the considerable saving it effects in steam consumption. On the larger works a condensing engine still further increases the efficiency of steam consumption. When, however, a single cylinder engine is installed some attention to the valve setting is necessary. All exhauster engines may be operated with a comparatively early "cut-off," and the admission of steam for the whole length of the stroke must be looked upon as unjustifiable extravagance. In the majority of cases the "cut-off" may be arranged at half-stroke, though many engines will be found working at three-quarters or seven-eighths. The later "cut-off" probably emanates from the fact that some engineers are of the opinion that closure at any earlier period is conducive to unsteady running; but if the fly-wheel is of sufficient proportions this will not be found to be the case.

FIG. 211.—ELECTRICALLY DRIVEN EXHAUSTER INSTALLATION.

Cases are known where engines are running at a quarter "cut-off," and with no undesirable effect on the "draw." When a "cut-off" is used, however, a rather larger engine is necessary; and for high-pressure steam it is certainly advisable to fit an expansion gear, so that a sharper and earlier effect may be obtained. With very low-pressure steam it is essential to work with admission during the whole stroke.

Running Speed

It is not generally realized that when regulating an exhauster the speed to be considered is not the actual number of revolutions performed by the drum per minute, but the peripheral speed of the tips of the blades. For a given number of revolutions per minute the peripheral speeds of (say) a 6-inch drum and a 4-feet diameter drum would be widely different, the blade tips travelling at a greatly increased linear velocity in the latter case. In both cases, however, the peripheral speeds should be approximately equal, and for exhausters of all sizes there is very nearly a constant peripheral speed, which should vary only between the limits of 650 and 850 feet per minute. Thus a 6-inch exhauster running at 350 revolutions per minute gives a peripheral speed of 650 feet per minute, and a 3-foot machine running at 70 revolutions per minute has also a peripheral speed of about 650 feet per minute.

Governing the Capacity

There are two standard methods of governing exhausters:—

(*a*) By inserting an automatically controlled by-pass between inlet and outlet.

(*b*) By automatically throttling the steam supply, or controlling the electric current.

When a gas engine drive is employed the first method only is practicable, as the speed of the engine cannot be varied to any great extent by the ordinary means of governing employed. Schemes for effecting this have certainly been suggested; but, at the most, the result is only partial, and the most convenient arrangement is to work the engine in conjunction with a countershaft to which a stepped pulley is fitted.

The ordinary arrangement of governing with a by-pass valve is shown in Fig. 212. The inlet and outlet of the exhauster are connected by a short length of pipe in which an ordinary butterfly valve, attached to a quadrant (Fig. 213) is inserted. The quadrant is then attached by a chain and lever to the bell of a small gasholder which is connected by a small service pipe (*F*) to the inlet main of the exhauster. The quantity of gas coming away from the retort house varies to some considerable extent at different periods of the day. Accordingly, the intensity of vacuum produced will also vary in ratio to the amount passing if the speed of the exhauster is permitted to remain constant. In this type of governing the speed of the engine is maintained fairly constant, and at a sufficient velocity to take the maximum quantity of gas coming from the retorts. When the quantity passing along the foul main undergoes reduction the vacuum becomes momentarily increased;

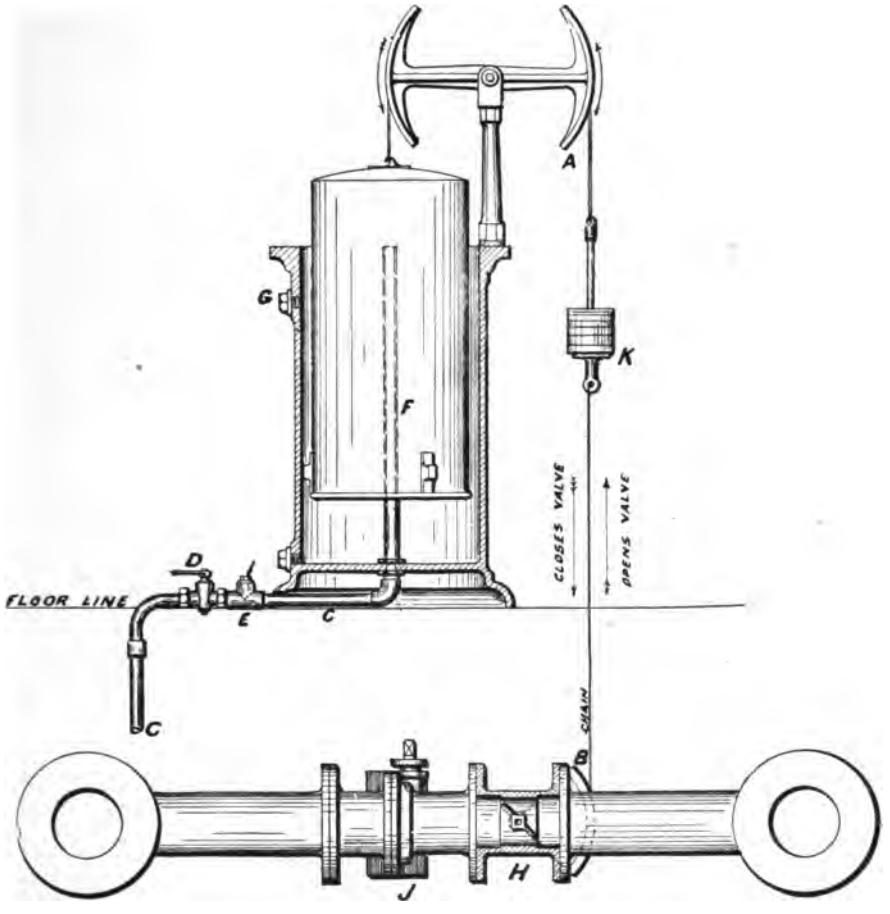


FIG. 212.—EXHAUSTER GOVERNING BY BY-PASS.

accordingly, the holder bell drops and operates through its link motion to open the by-pass valve. In this way gas is sucked back from the outlet to the inlet, and compensates for the falling off in the quantity coming from the retorts—thus the original vacuum is maintained. In the same way, as the quantity of gas passing along the foul main increases the vacuum momentarily decreases, with the result that the holder bell rises and closes down the by-pass valve until the normal "draw" is given. The method is certainly effective, but care is necessary to see that the exhauster is running at a sufficient speed to deal with the *maximum* quantity of gas likely to pass at any time from the retorts, for the governor cannot increase the speed of the engine should this be insufficient at any period. Fig. 214 shows a complete

FIG. 213.—QUADRANT AND VALVE.

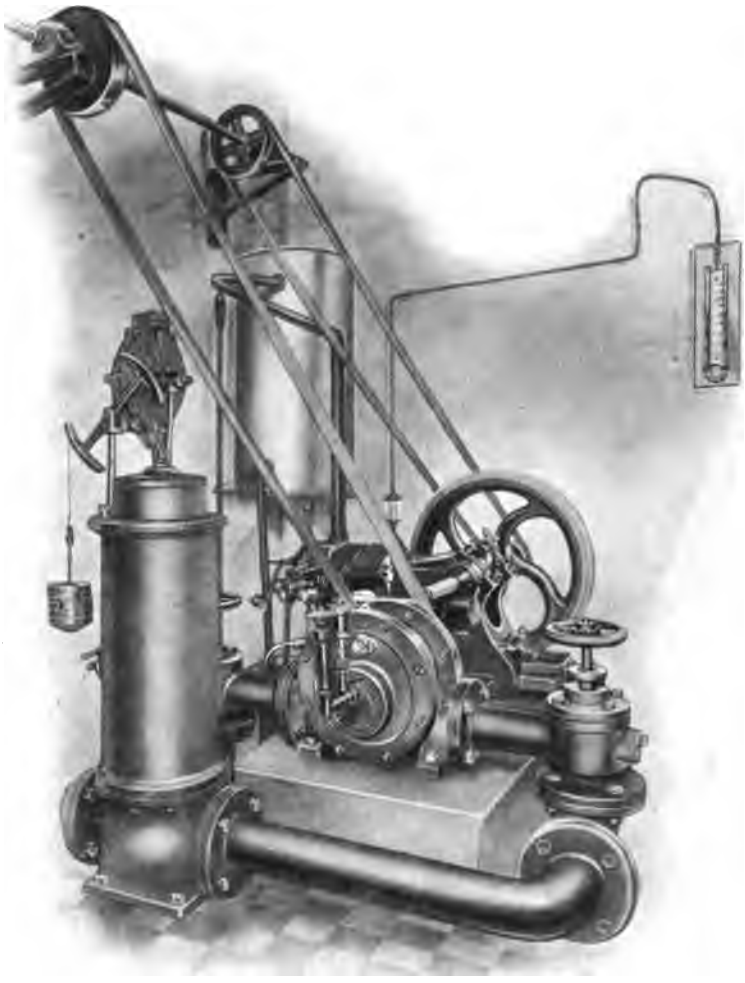


FIG. 214.—COMPLETE EXHAUSTER INSTALLATION SUITABLE FOR A SMALL WORKS.

gas-driven exhausting plant with by-pass governor suitable for a small works.

There is little doubt that, when the size of the plant permits, exhauster governing can be most effectively carried out by varying the speed of the engine employed for driving. This is simply effected by employing a gasholder bell the interior of which is in communication with the vacuum side of the exhauster. Buoyancy is imparted by means of air-floats placed at the base of the bell, whilst the upward or downward movement of the bell is conveyed by link motion to the throttle valve of the engine. Briefly explained, the operation of the governor is as follows:—Should the quantity of gas passing to the inlet of the exhauster decrease, then the

intensity of vacuum in the inlet main will increase. But the service pipe (*A*, Fig. 215) transmits this increase of vacuum to the interior of the bell, which, accordingly, is pulled downwards. The downward movement of the bell then operates through the link-motion to close the throttle valve (*H*) slightly so that the speed of the engine is reduced in accordance with the amount of gas coming along. In the same way, when the quantity of gas increases, the vacuum on the inlet falls, with the result that the bell ascends and opens the steam throttle to the required extent. By adjusting the cock placed at *R*, on the top of the bell, the rate at which the bell rises and falls may be regulated. In some instances steadiness of movement is assured by introducing the principle of the "dash-pot."

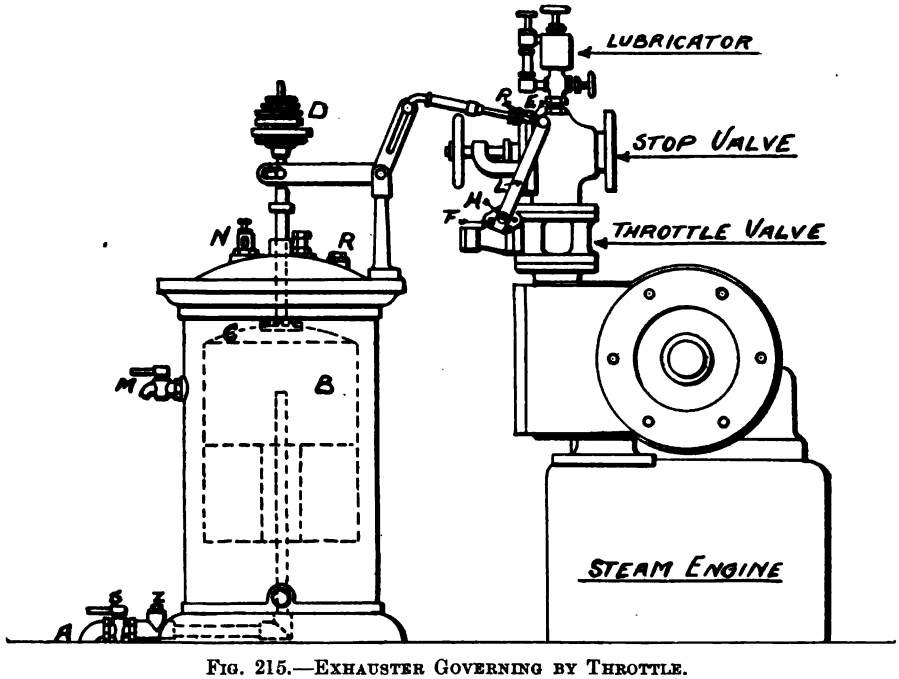


FIG. 215.—EXHAUSTER GOVERNING BY THROTTLE.

In laying down exhauster installations it is frequently arranged that both by-pass and throttle governors shall be provided. On large works where a number of exhauster units are employed, there is no necessity for a by-pass governor, for, according to the make, exhauster sets are started up or shut off and the whole of the governing can be done by steam regulation. On small and medium-sized works, however, where only duplicate machines are in use, a single exhauster has probably to deal with the maximum winter and minimum summer make. In this case the exhauster is usually installed to allow room for future extension; consequently, without the by-pass governor it would have to run at an inconveniently low speed when dealing with the minimum make. In such cases it is preferable, therefore, to supply a by-pass governor, which is adjusted from time to time according to the season,

whilst the throttle governor controls the speed of the engine according to the varying makes during the 24 hours.

The Lubrication of Exhausters

The lubrication of the exhauster is a point requiring very careful attention, for endless trouble may follow the use of unsuitable oils. For most purposes the best lubricant is a mixture of refined creosote and mineral oil—one part of the former to three of the latter. A heavy oil should always be used, also an oil that will act as a solvent to the tar, such as a good mineral oil, rather than a vegetable oil which will thicken with the tar. The temperature of the gas, the quantity of suspended tar, and whether the gas is clean or foul are all important factors from the point of view of lubrication; and experience is, perhaps, the most reliable guide. When the exhausters are preceded by tar extractors it will be found preferable to use an ordinary engine-oil of good quality. The tar vesicles present in the gas possess very important properties in relation to the lubrication of the exhauster, and it is important to ensure that the necessary fluidity of the tar is maintained. Dr. Carpenter has emphasized the value of the tar present by showing that, when the exhausters are placed prior to the condensers in sequence, not a drop of lubricating oil is necessary.

Special apparatus for the lubrication of exhausters is now nearly always employed. The forms most generally made use of are:—

(*a*) Ordinary self-contained drip-feed.

(*b*) Pressure system, embodying the use of a reservoir from which the oil is expelled by the pressure of gas at the outlet of the exhauster.

(*c*) Mechanical appliances, such as miniature pumps driven by gearing or belting from the exhauster shaft.

One of the last-named devices is shown in Fig. 216. It consists of an oil pump which is driven by gearing from the main shaft of the exhauster. Above the pump is an oil reservoir from which the oil is sucked, and pumped under pressure to the various parts requiring lubrication. The pump may be fitted with a single plunger,

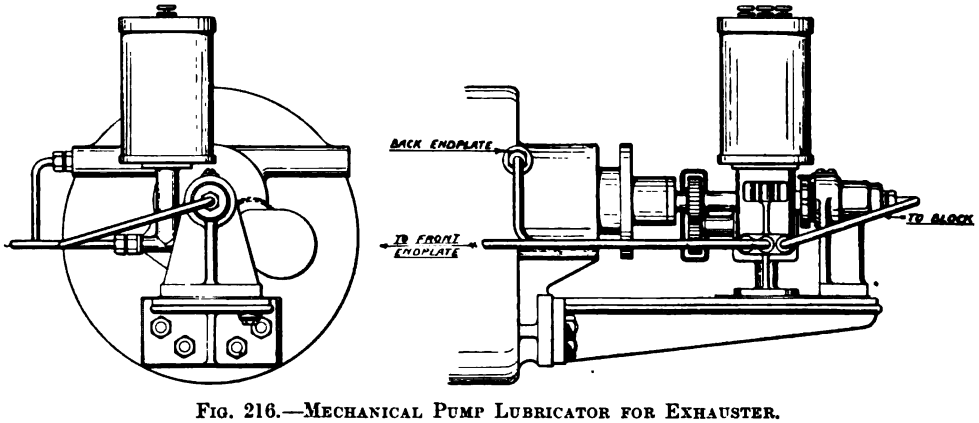


Fig. 216.—Mechanical Pump Lubricator for Exhauster.

or may be of the multiple type according to the number of points at which lubrication is desired. It should be noted that whatever form of lubrication is made use of it is essential that the oil be filtered before use.

The several points at which an exhauster should be lubricated depend largely upon the type of the machine. Taking, however, as an instance one of the three or four blade types such as Waller's (Fig. 208), it will be seen that the inner drum is supported and rotates in recessed covers, therefore lubrication is required at these points. The hinges upon which the blades are carried upon the central spindle are lubricated by means of an oil hole provided by boring through the whole length of the spindle, oil being forced through this duct by an automatic or hand pump. In the case of the old pattern two-blade Beale exhauster the inner drum is supported by the shaft, which is carried in outside bearings; these require lubrication, as do the segments which rotate in grooves in the covers. The latest pattern Beale machine is provided with a recessed back cover which requires lubrication, the driving shaft is supported by an outer bearing which must also be lubricated, whilst the steel spindle supporting the centre block upon which the blades rotate is provided with a hole for injecting oil. When possible, a continuous flow of oil, as given by one of the mechanical lubricators, should always be arranged for, this being very much more effective than an intermittent supply. The distribution must, moreover, be uniform, as a dry portion where contact occurs quickly results in heating and subsequent erosion of the surfaces.

Precautions against Stoppage

Owing to the seizure of a bearing, the slipping of a belt, the burning out of a fuse, or some other unlooked-for cause, an exhauster is liable to pull-up at short notice. This, of course, should not occur if the machine is properly attended to; but, nevertheless, it is an emergency which must always be provided for. In addition to duplicate plant some means should be provided for guarding against the undue pressure which would otherwise be thrown upon the retorts and the apparatus between them and the exhauster. A usual method is to insert in a by-pass pipe connecting inlet and outlet a safety flap-valve such as that shown in Fig. 217. In the ordinary way the outlet pressure holds the valve against its seatings, but should the exhauster stop the inlet pressure will, after a time, exceed that on the outlet, so that the valve is forced open, giving a free way for the gas. It will be realized, however, that only temporary relief is afforded before the pressure of the whole apparatus will be thrown on the retorts. The flap valves are usually fitted with a handle, as shown, so that they may occasionally be jarred in order to ensure that sticking will not occur.

On the rare occasions when the exhausting plant breaks down it is unreasonable to expect that no loss of gas whatever need take place, and the most simple and safe means of providing against such a contingency is that of inserting a safety seal in the main leading from the retort-house to the exhauster. This seal can be regulated to some definite depth—usually about 6 to 8 inches—thus only a small pressure will be exerted upon the apparatus before the gas blows away. The seal

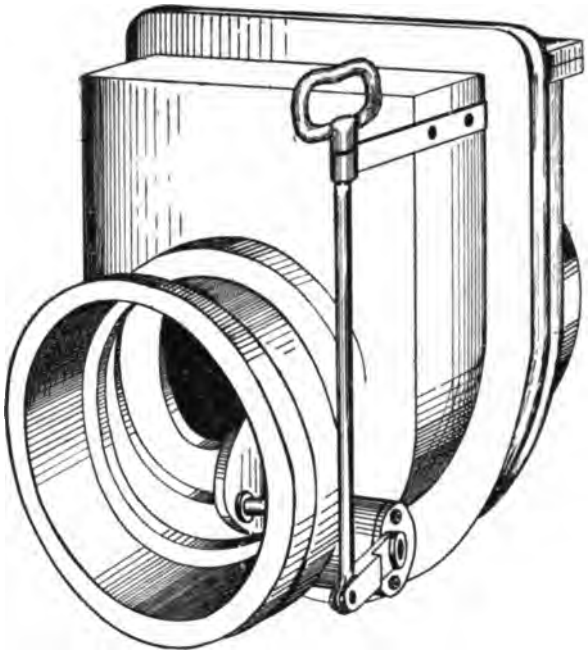


FIG. 217.—SAFETY FLAP-VALVE.

should be arranged at some point in the open where there will be no chance of the escaping gas igniting. In making use of a seal of this kind it is necessary to ensure that the blow-off pipe is sealed to a greater depth than the maximum possible "draw" at this point; otherwise air will be sucked in.

CALCULATION OF CAPACITY

Figures given by makers for the capacity of exhausters denote the amount of gas passed at normal temperature. The exhauster has, however, to deal with an amount of gas varying from 5 to 10 per cent. in excess of this rated quantity. In addition, "slip" past the blades is a fairly considerable item, for which further allowance has to be made. The amount of "slip" occurring is entirely dependent upon the difference of pressure between the inlet and outlet of the exhauster, and is independent of speed. But it may be taken as a general rule that as speed increases the proportional "slip" undergoes reduction. In calculating the capacity of exhausters it is customary to make an allowance of 15 to 20 per cent. for "slip," according to the size of the machine.

The calculation of the capacity of an exhauster is not so simple as might at first sight be supposed. Considering an ordinary four-blade machine it must be remembered that the capacity is not the whole space swept out by each blade per revolution. The amount of gas carried forward by each pair of blades is the

greatest volume which exists at any time between the two blades. By reference to Fig. 218 it can be seen that at each revolution a volume of gas having a cross-sectional area equal to the shaded portion of the figure is carried from inlet to outlet by each pair of blades; and in one revolution of the exhauster this volume is taken in and delivered four times. When considering a two or three-blade machine the volume between the blades (for a given size) is, of course, greater than with the four-blade; but then it is only displaced two or three times in one revolution instead of four times.

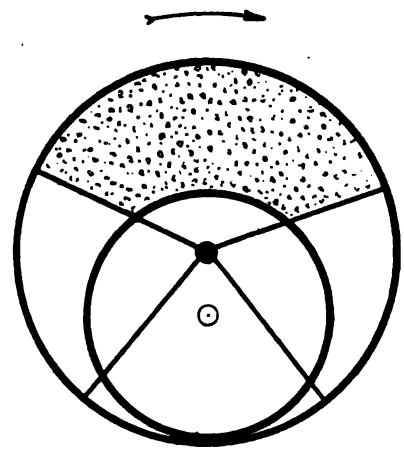


FIG. 218.

For a four-blade exhauster the following method of calculating capacity may be used, but it cannot be said to be closely accurate when very large or very small sizes are under consideration.

Let D = the inside diameter of outer drum in feet.
L = length of drum in feet.
N = Revolutions made per minute.
Q = Cubic feet of gas passed per hour.

Then $Q = 65D^2LN$.

This gives the gross capacity, from which 20 per cent. should be deducted for "slip."

The capacity of modern exhausters has been increased to a certain extent by the introduction of relief-port passages which enable the blades to continue drawing for a longer period and provide a greater area for the issuing gas. It is questionable, however, whether these passages are perfectly satisfactory.

DRIVING POWER REQUIRED

The motive power is the largest item in the running costs of exhausters. As regards the horse-power required for any one installation it is almost impossible to lay down a hard and fast rule, for so much depends upon the conditions under which the plant is working. A mere table of powers is, therefore, apt to be misleading. The power varies considerably; for instance, an exhauster made to pass 100,000 cubic feet per hour at its standard speed would have about 65 to 70 per cent. efficiency if working against 30 inches to 60 inches back-pressure. If, however, the machine was put to work to pass 25,000 cubic feet per hour, the power required could not be taken in the same ratio to the gas passed, for the amount of power lost would bear a much larger ratio to the gas passed than in the first case. Hence the efficiency of the machine when dealing with small quantities will be much lower. There is no fixed rule as to what to allow for efficiency in such cases, and much depends on the type of machine under consideration. In practice, it is usual to treat each case on its merits, to suit the prevailing conditions. Some idea of the

probable horse-power required may, however, be obtained from the following table, compiled by E. B. Donkin:—

HORSE-POWER REQUIRED TO PASS GAS AGAINST VARIOUS PRESSURES.
(Friction of Exhauster neglected.)

Capacity per Hour.	TOTAL PRESSURE OF GAS IN INCHES OF WATER.										
Cubic feet.	6	9	12	15	18	20	24	30	36	40	50
5,000	0·08	0·12	0·16	0·19	0·24	0·26	0·31	0·39	0·47	0·53	0·66
10,000	0·16	0·24	0·31	0·39	0·47	0·53	0·63	0·79	0·95	1·05	1·31
15,000	0·24	0·36	0·47	0·58	0·71	0·79	0·94	1·18	1·42	1·58	1·97
20,000	0·31	0·47	0·63	0·79	0·95	1·05	1·26	1·58	1·90	2·10	2·63
25,000	0·39	0·59	0·79	0·98	1·18	1·31	1·58	1·97	2·37	2·63	3·29
30,000	0·48	0·71	0·94	1·18	1·42	1·57	1·89	2·36	2·83	3·15	3·94
40,000	0·62	0·94	1·26	1·58	1·90	2·10	2·52	3·15	3·78	4·21	5·26
50,000	0·79	1·18	1·58	1·97	2·36	2·63	3·15	3·94	4·73	5·25	6·57
60,000	0·94	1·41	1·89	2·36	2·84	3·15	3·79	4·73	5·67	6·30	7·89
80,000	1·24	1·84	2·52	3·16	3·80	4·20	5·04	6·30	7·56	8·42	10·5
100,000	1·58	2·37	3·16	3·94	4·73	5·26	6·31	7·89	9·47	10·5	13·15
150,000	2·37	3·54	4·72	5·90	7·09	7·87	9·46	11·8	14·2	15·8	19·7
200,000	3·16	4·74	6·32	7·88	9·46	10·5	12·6	15·8	18·9	21·0	26·3
250,000	3·95	5·92	7·90	9·85	11·8	13·1	15·7	19·7	23·6	26·2	32.9
300,000	4·74	7·11	9·48	11·8	14·1	15·7	18·9	23·6	28·4	31·5	39·4

The additional allowance for friction will vary from 40 to 100 per cent. of the figures given by the above table. As an illustration of this item, the following examples are given:—

PERCENTAGE TO ADD TO POWERS GIVEN IN ABOVE TABLE IN ORDER TO FIND HORSE-POWER TO DRIVE EXHAUSTER.

Capacity per Hour.	Back-pressure.	Add to previous Power.
10,000 cubic feet	12 inches	100 per cent.
20,000 „ „	18 „	90 „
50,000 „ „	24 „	70 „
100,000 „ „	30 „	50 „
200,000 „ „	36 „	45 „
300,000 „ „	50 „	40 „

Thus for an exhauster passing 100,000 cubic feet against 30 inches back pressure an engine of about 12 b.h.p. would suffice, although it is always as well to allow an additional margin of 25 per cent., bringing the total brake horse-power up to 15.

Steam Jet Exhausters

Steam jet exhausters working on the injector principle are comparatively rare features of the modern gasworks in this country, although they continue to find a certain amount of favour on the Continent. A notable instance of the employment of this type of exhauster is the Gloucester gasworks, where apparatus of the kind has been in use since 1877, when the works were built. First introduced by Cleland, the steam jet was afterwards improved by Körting, and is seen in Fig. 219. Steam at about 50 lb. pressure is projected through a series of truncated cones gradually increasing in size. The gas is drawn in through spaces at the nozzles of the cones and is carried forward by the pressure of the steam. Care should be taken to ensure that dry steam only is used, and this is afterwards extracted from the gas by condensing apparatus. The capacity of the exhauster may be regulated within comparatively wide limits by an adjustable needle-valve at the steam inlet, and by a moveable sleeve which opens or closes the gas inlet

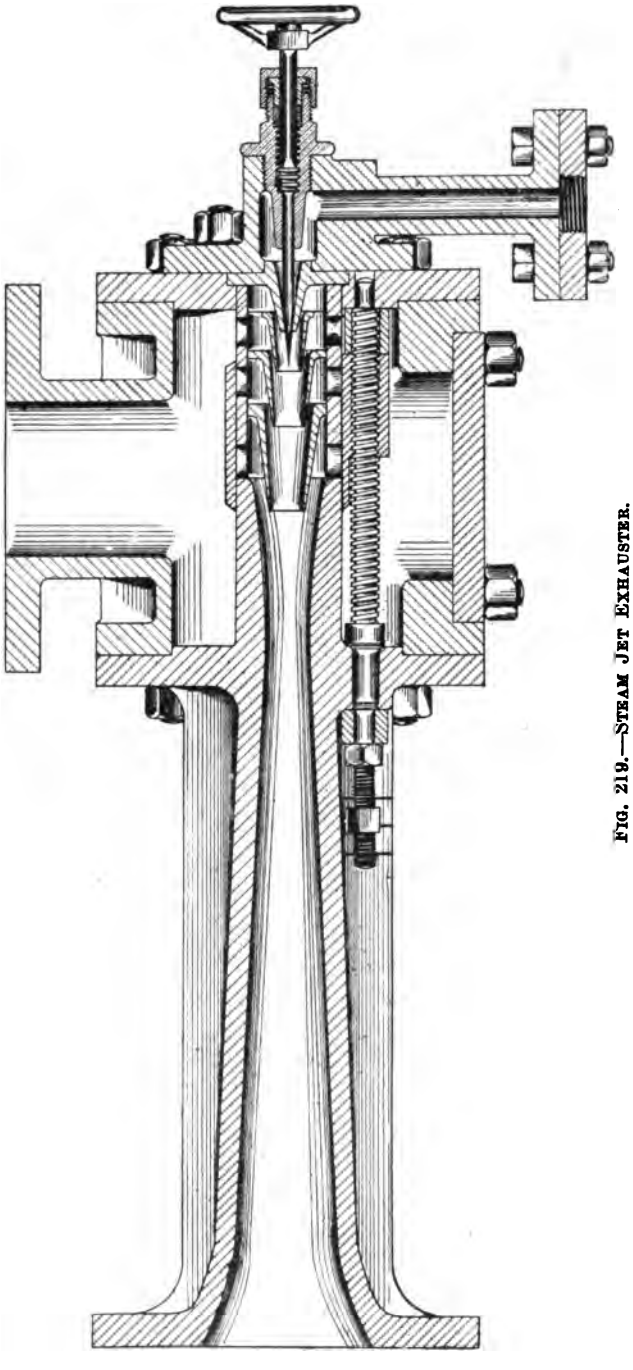


Fig. 219.—Steam Jet Exhauster.

ports. The chief merits of this type of exhauster are that pulsation is entirely avoided, and there are no constantly moving mechanical parts to give rise to wear and tear. On the other hand, there is the expense of providing additional condensers, whilst steam consumption is high. The jet may be interposed at various points in the series of apparatus. In some cases it is preferred to place it in the foul main, almost immediately after the hydraulic main, others make use of it after the condensers, but at Gloucester it comes just prior to the dry purification plant. Some advocates of the steam-jet exhauster have said that it gives rise to a direct increase in illuminating power equal to as much as three-quarters of a candle. It is difficult, however, to see on what grounds such a gain in quality could take place. At the Gloucester works the expenditure on wear and tear over a period of about 30 years amounted to £5.

Turbo-Exhausters

The chief drawback to the ordinary rotary exhauster is the necessity for a considerable amount of rubbing contact and the large frictional area brought into play, with a consequent reduction in efficiency. In recent years these difficulties

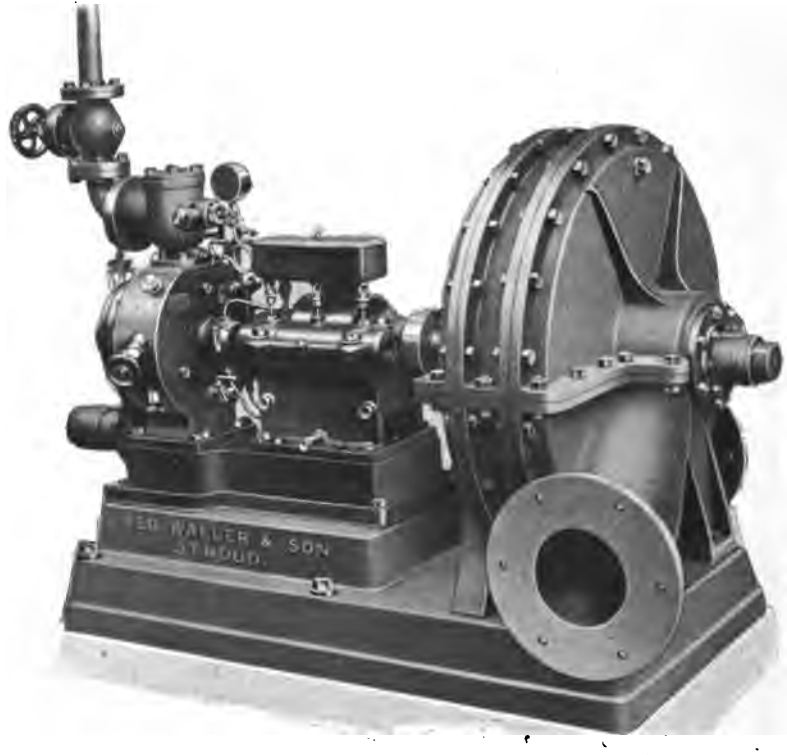


Fig. 220.—Two-stage Waller Turbo-Exhauster.

FIG. 221.—THREE-STAGE WALLER EXHAUSTER.

have been overcome by the introduction of the high-speed machine working on the fan principle and providing large clearances. A further advantage offered by the centrifugal fan exhauster is its greater volumetric capacity in proportion to the floor-space occupied.

In order to deal with pressures commonly met with on gasworks, it is generally necessary to build these machines with two or more impellers which rotate on a common axis but in separate cells. By means of suitable passages the gas is passed from cell to cell in series until it is discharged from the machine at the requisite pressure, this pressure being the sum of the amounts by which it is increased at each stage. The intensity of this increase of pressure per stage is dependent upon the diameter and speed of the impellers, and also upon the specific gravity of the gas at the time of its being passed through the machine. Constructional difficulties inherent to this type of exhauster have, up to the present, restricted its use to works with a large output. So far it has been found impracticable to build them in sizes which will deal with the requirements of small or medium-sized works with the efficiency and reliability which characterize the ordinary rotary type.

As might be expected the several designs now to be had differ considerably, but many are based on the principles of Professor Rateau, who has devoted considerable time to the study of the subject. Figs. 220 and 221 show the Waller type of turbo-exhauster, the two-stage machine being driven by steam turbine,

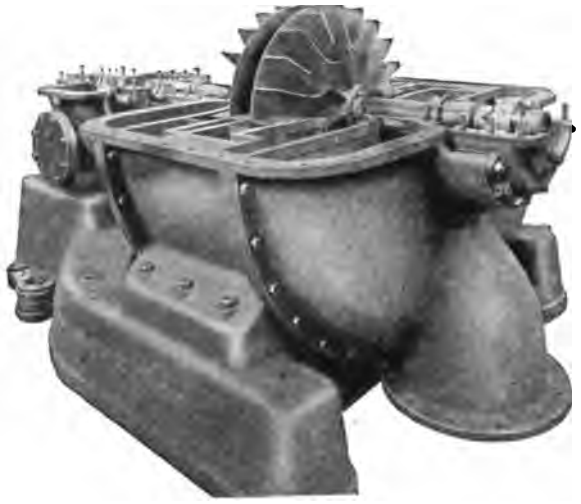


FIG. 222.—BRITISH THOMSON-HOUSTON TURBO-EXHAUSTER.

and the three-stage by electrical motor. The impellers of these machines are built up from steel plates bolted to a cast-iron centre, whilst the spindles are of steel, running at the driving end in white metal bearings with oil-ring lubrication, the outer ends running in ball bearings. A ball bearing is also provided at this end to take up the axial thrust of the spindle due to the pressure of the gas on the impellers. The exhauster and prime mover are mounted on a cast-iron box section. The machine shown in Fig. 220 is driven by a de Laval turbine running at 4,000 revolutions per minute, and will pass 50,000 cubic feet of gas per hour against a pressure of 30 inches. The larger machine (Fig. 221) is rated for a capacity of 170,000 cubic feet per hour against a pressure of 42 inches. Owing to the high speed at which turbo-exhausters have to run, they are particularly suited for being driven direct by electric motor or steam turbine without the employment of intermediate gearing. Another type of fan exhauster is shown in Fig. 222. This is the British Thomson-Houston machine driven by a Curtis impulse-type steam turbine through a flexible coupling. The exhauster is of the two-stage type, and is capable of dealing with 500,000 cubic feet of gas per hour against a pressure of 40 inches. In this case the impellers are placed back to back in order to eliminate end-thrust. Fig. 223 shows one of the impellers, which are solid steel castings, the blades and hub being in one piece, with the exception of the inlet ends which, being twisted to allow free entry of the gas, are mounted on a small extension hub. On leaving the impeller the gas passes through a series of exit guide blades, which convert the velocity head into pressure head. As regards initial cost this is, on an average, about 50 per cent. less than that of an ordinary rotary installation of the same capacity. Owing to the high rate of speed, pulsation with this type of exhauster is almost entirely eliminated.

FIG. 223.—EXHAUSTER IMPELLER.

EXHAUSTERS PRIOR TO CONDENSERS

The position of the exhauster is entirely arbitrary. In almost all cases, however, it will be found in sequence between the condensing and washing plant. Some engineers prefer to place the machine either before the condensers (so that condensing takes place under pressure), or after the washers (so that both condensers and washers are under a vacuum). The practice of condensing under pressure has assumed some importance, and finds a stout advocate in Dr. Carpenter. The problem of the most effective means of lubricating an exhauster is always a vexed one, and is said to be more troublesome when the light oil tars have been removed from the gas in the process of condensation. When, however, the exhauster is placed prior to the condensers, so that it is operated at a temperature of about 140° Fahr., no lubricant is necessary, the condition of the gas being sufficiently oily to ensure smooth running of the machine. By placing the exhauster at a point nearer to the hydraulic main a shorter length of main under vacuum is assured, so that there is less probability of the intake of air through defective joints. At the present day, however, the latter consideration has lost a good deal of its former significance, owing to the reduction in standards of illuminating power, and the fact that lime purification is obsolescent. The disadvantage attached to exhausting hot gas is that owing to its increased temperature the bulk of the gas is augmented, hence additional exhauster capacity is necessary. If the average temperature of the gas is about 140° Fahr., the additional capacity required (compared with the ordinary practice of exhausting at 70° Fahr.) will amount to about 15 per cent.

CHAPTER XIV

THE PRELIMINARY PURIFICATION OF COAL GAS

THE purification of coal gas commences directly the gas reaches the hydraulic main, by which time it has undergone a considerable drop in temperature. At this point some of the impurities will be washed from the gas by the deposition of a portion of the aqueous vapour and by its passage through the hydraulic seal. The impurities in crude coal gas at this stage may be summarized as follows :—

(1) Suspended tarry matter and condensible hydrocarbons.
(2) Ammonia.
(3) Sulphuretted hydrogen.
(4) Carbon disulphide and other sulphur compounds.
(5) Carbonic acid, by which term carbon dioxide (CO_2) is generally known on gasworks.
(6) Hydrocyanic acid, usually spoken of as cyanogen.
(7) Naphthalene.

Of these, the last three can scarcely be classified as impurities, and there is no statutory obligation to remove either these or No. 4. Whilst it is in all cases to the engineer's own interest to reduce the naphthalene content to such a quantity as can be carried by the gas without deposition, the removal of cyanogen and sulphur compounds is (owing to the very small quantities in which they are present) not so imperative, and is only carried out in rare instances. Carbon dioxide, though invariably classified as such, is in no sense an impurity, but may be looked upon as an inert diluent having a certain deteriorating influence upon the illuminating and heating values of the gas (*see* page 393).

In the preliminary purification of coal gas by wet methods it is the removal of a portion of the sulphuretted hydrogen and carbon dioxide with which we are chiefly concerned. At the same time the last traces of suspended tar must be eliminated. In order to understand the principles upon which the process is based, it is necessary to consider the nature of the various substances present in the crude gas, *i.e.* whether they are acid or alkaline. Thus we have :—

Ammonia—alkaline.
Carbon dioxide—acidic properties.
Sulphuretted hydrogen—acidic properties.
Hydrocyanic acid—acid.

In the first instance, advantage is taken of the powerful affinity possessed for ammonia by water which, at normal temperature and pressure, is capable of absorbing about 780 times its own volume of ammonia gas. Thus, treatment of the crude gas with water, in special vessels known as washers and scrubbers, affords a ready

means of removing this impurity. Water also possesses some affinity for carbon dioxide and sulphuretted hydrogen, but its capacity in this direction is but slight, one volume absorbing about three and a quarter volumes of sulphuretted hydrogen, or one volume of carbon dioxide. Carbon disulphide gas is also soluble in water, but to a very small extent, amounting to about one-thousandth part of the volume of water. Advantage is taken of the fact that the ammonia solution formed, being of an alkaline nature, is capable of ready reaction with the acid impurities in the gas. Thus carbon dioxide, the strongest acid present, and sulphuretted hydrogen, are absorbed, with the formation of certain definite salts which are themselves soluble in the water. In the ordinary sense ammoniacal liquor consists of water containing in solution a certain proportion of these salts.

It is necessary to emphasize that the quantity of ammonia which water can absorb is not entirely dependent upon temperature, for solubility also varies in direct proportion to the pressure of the ammonia gas. If pure ammonia gas is in contact with water at normal temperature and pressure (60° Fahr. and 30 inches Bar.) then the water is capable of absorbing an amount equal to 780 times its own volume. In crude gas, however, the proportion of ammonia to the whole volume is trifling, hence the pressure it will exert is only in proportion to the extent of its presence. For instance, if ammonia is present to the extent of one per cent. of the whole, then the pressure it exerts will amount to merely 0·01 atmospheres, at which pressure very little affinity exists between it and the water. It is this fact which explains the necessity for using a comparatively large quantity of water per ton of coal carbonized (*see* page 356), and shows why the question of time contact is one which must be considered in the design of washers and scrubbers.

Ammonia in crude coal gas is usually found to the extent of about 1·5 per cent. by volume, and of this amount from a third to one-half will have been washed out by the aqueous vapour and have been deposited by the time the gas has reached the outlet of the condensers. In this respect the figures of Hunt, who found the distribution of ammonia as follows, are of interest :—

Ammonia removed by	condensation	. . . .	42·7	per cent. of total.
„ „	first scrubber	. . . .	43·3	„ „ „
„ „	second „	. . . .	14·0	„ „ „

When gas containing sulphuretted hydrogen and carbon dioxide comes in contact with a solution of ammonia, the amount of the acid gases absorbed may be sufficient to give rise to a neutral or normal salt, or absorption may continue until the ammonia solution contains about 20 per cent. more of the acids than is sufficient to give the neutral salts. Hence, both acid and normal salts result as follows :—

Ammonia and Carbon Dioxide—

(1) $2NH_4OH + CO_2 = (NH_4)_2CO_3$ (ammonium carbonate) $+ H_2O$. Normal.

(2) $NH_4OH + CO_2 = NH_4HCO_3$ (ammonium bicarbonate). Acid.

Ammonia and Sulphuretted Hydrogen—

(1) $2NH_4OH + SH_2 = (NH_4)_2S$ (ammonium sulphide) $+ 2H_2O$. Normal.

(2) $NH_4OH + SH_2 = NH_4HS$ (ammonium hydrosulphide) $+ H_2O$. Acid.

Actually, the acid salts are not formed direct, as shown above, but from further absorption of acid gases by the normal solutions, as follows :—

$(NH_4)_2CO_3 + H_2O + CO_2 = 2NH_4HCO_3$.

$(NH_4)_2S + SH_2 = 2NH_4HS$.

THE COMPOSITION OF GAS LIQUOR

The liquor deposited in the hydraulic main and condensers is generally characterized as "virgin liquor," which signifies that the water in which the salts are dissolved emanates from the coal and not from external sources. In the ordinary way the yield of virgin liquor varies from 10 to 14 gallons per ton of coal carbonized. The hydraulic main liquor differs considerably from that obtained in the washing plant, chiefly owing to the fact that the temperature at this point (about 140° Fahr.) renders many of the compounds which are found at the lower temperatures unstable. Thus the salts formed as in the above reactions, *i.e.* the carbonates and sulphides, are present in only small quantities, there is little free ammonia in comparison with the amount in the scrubber liquor, and fixed ammonia salts may predominate.

Ammonia in gas liquor may be combined in two distinct ways, first as easily decomposable compounds such as carbonates and sulphides and, secondly, as more stable compounds which will not undergo decomposition by heating, but which require the addition of a caustic alkali to liberate the ammonia from them. In the former case, the ammonia is combined with the weaker acidic gases CO_2 and SH_2 and is known as "free" ammonia. In the latter case it is combined with stronger acids, such as hydrochloric and sulphuric, and is then called "fixed" ammonia. The "fixed" ammonium salts in gas liquor are the outcome of the combination of ammonia with the minor impurities in the crude gas and are derived to some extent from oxidation. In general, the final mixture of gas liquor obtained in the storage well contains from 75 to 80 per cent. of the "free" salts and from 20 to 25 per cent. of "fixed" salts, the probable constituents being as follows :—

THE COMPOSITION OF GAS LIQUOR

Water containing in solution :—

Ammonium carbonate	"Free" ammonia 75 to 80 per cent. of total ammonia.
,, bicarbonate	
,, carbamate	
,, sulphide	
,, hydrosulphide	
,, cyanide	
,, polysulphide	
,, chloride	"Fixed" ammonia 20 to 25 per cent. of total ammonia.
,, sulphocyanide	
,, sulphite	
,, thiosulphate	
,, sulphate	
,, ferrocyanide	
,, acetate	

Also phenols, amines and other nitrogenous bodies.

It does not follow that gas liquor will contain every one of the above salts; in fact, some of those included are only met with on rare occasions. Ammonium carbamate, $CO(ONH_4)NH_2$ is deposited as a white solid when CO_2 and ammonia meet. It is easily soluble in water, but is probably present in only minute quantities in gas liquor, for, when dissolved, it is soon converted into carbonate. As regards the "fixed" salts, these are largely accounted for by ammonium chloride, which owes its presence to the common salt (sodium chloride) present in the original coal. The amount of salt varies considerably according to the class of coal used, the maximum proportion in the coal being about 0·25 per cent. Ammonium chloride is a particularly unwelcome compound, for, in addition to its deleterious effects on the fireclay of the retorts,[1] it has—in the gaseous state—a marked corrosive action on the steelwork of the hydraulic main, etc. When deposited in the solid state it may give rise to considerable trouble, due to the stoppage of pipes, and in some cases special means have been introduced for dealing with it.[2]

Ammonium cyanide is present only in traces, and is very generally absent altogether. The ferrocyanide is also of rare occurrence, so much so that, during an examination of various liquors extending over a period of five years, conducted by the chief inspector under the Alkali Act, it was only identified with certainty on one occasion. Ammoniacal liquor is considerably affected by oxidation, so that its ultimate constituents are influenced in some degree by the amount of oxygen present in the gas. A process of gradual oxidation from one compound to another takes place, the final salts obtained depending upon the extent to which the oxidation has occurred. Ammonium polysulphide and thiosulphate are the first products of oxidation, these being formed from ammonium sulphide, although, in the case of the former, the action is more mechanical than chemical. Oxidation, then, proceeds progressively, so that in turn the thiosulphate, sulphite and lastly, sulphate are formed, whilst in certain cases free sulphur may be deposited. The sulphite is usually only present in faint traces, which is probably accounted for by the fact that solutions of polysulphide and sulphite react to form sulphide and thiosulphate: $(NH_4)_2S_2 + (NH_4)_2SO_3 = (NH_4)_2S + (NH_4)_2S_2O_3$. At the same time ammonum thiosulphate may be formed by reaction between the sulphite and sulphide:— $4(NH_4)_2SO_3 + 2(NH_4)_2S = 3(NH_4)_2S_2O_3 + 6NH_3 + 3H_2O$. Lunge asserts that ammonium polysulphide cannot exist in ordinary ammoniacal liquors, since it reacts with sulphites and cyanides. At one time there was some doubt as to whether gas liquor contained any actual free ammonia (*i.e.* dissolved NH_3), but investigators such as Gerlach and Tieftrunck have shown this to be the case. Owing to the fact that acetylene is of a slightly acid nature, ammonium acetate (CH_3COONH_4) may in some cases be found in gas liquor. When liquor is distilled with an alkali (lime) for the manufacture of sulphate of ammonia, the final traces of ammonia are seldom expelled, so that some slight loss, amounting, under best conditions, to about 0·1 per cent., is inevitable. This is in some measure due to the fact that certain of the ammonia-bearing compounds (such as the amine bodies) require rather more energetic treatment to bring about complete decomposition.

[1] *See* Chapter VI, page 148. [2] *See* Chapter VII, page 176.

From the foregoing remarks, it will be gathered that the final composition of ammoniacal liquor depends upon—

(*a*) The class of coal carbonized.

(*b*) The amount of salt in the coal.

(*c*) The temperature of distillation.

(*d*) The means employed for separating liquor and gas.

(*e*) The temperature to which the liquor is subjected.

(*f*) The amount of oxygen in the gas, the amount of air drawn in on the inlet of the exhauster, and the extent to which the liquor is exposed to the atmosphere.

Item (*d*) is one which is frequently overlooked, and may have some considerable influence on the amount of ammonia present in the crude gas. For instance, when tar towers are in use the ammonia in the gas at the outlet of the condensers is frequently lower than 200 grains per 100 cubic feet, in contrast with about 300 grains when the system of a separate draw-off to each hydraulic is installed. The reason would appear to be that in the case of tar towers the maintenance of the seal is ensured by running liquor into the tower alone. When weir valves or other individual means are in use the liquor is usually laid on to each hydraulic, and by giving rise to splashing sets free ammonia, which is accordingly carried forward by the gas. In the ordinary way the hydraulic main liquor contains about 50 per cent. of its ammonia in the fixed form, chloride and sulphocyanide predominating. At the present day, however, it is a growing practice to circulate the liquor repeatedly through the hydraulics, and in such cases the fixed content will be considerably increased, so that it may amount to as much as 80 per cent. of the ammonia present.

The proportion of ammonia contained in gas liquor is in reality quite small.

In normal cases the total ammonia varies from 1·5 to 2 per cent., being apportioned as follows :—

Free ammonia	1·2 to 1·6 per cent.
Fixed ammonia	0·3 to 0·4 „ „

As regards CO_2 and SH_2 the following figures may be taken as illustrating average conditions :—

CO_2 in gas liquor	1·3 to 2 per cent.
SH_2 „ „	0·1 to 0·6 „ „
Sulphur „ „	0·5 to 0·7 „ „

It is difficult to lay down any hard and fast figures in connexion with the manner in which the ammonia is distributed, but in general it will be accounted for somewhat as follows. The manner in which the sulphur is combined is also given.

Distribution of Ammonia in Gas Liquor.

"Free"	Ammonium sulphides	6 per cent. of total ammonia.
	„ carbonates	74 „ „ „
"Fixed"	„ chloride	15 „ „ „
	„ sulphocyanide	1·75 „ „ „
	„ thiosulphate, sulphite, etc.	3 „ „ „
	„ sulphate	0·25 „ „ „

DISTRIBUTION OF SULPHUR IN GAS LIQUOR.

Sulphur combined with free ammonia as sulphides	55 to 75	per cent. of total.
„ „ „ fixed ammonia as sulphocyanide	15 to 25	„ „
„ „ „ „ „ as sulphate	1 to 5	„ „
„ „ „ „ „ as thiosulphate	5 to 15	„ „
„ „ in other forms (polysulphide, etc.)	1 to 5	„ „

The ammonia present in coal gas has provided the gas engineer with a simple means of eliminating the chief impurities in the gas, but there is a limit to the extent of the purification which can be carried out through its agency, for the amount of the alkali present in crude gas is only in the neighbourhood of 1·5 per cent. by volume. Of this, about one-fourth to one-fifth is combined as fixed salts, thus the surplus available for the removal of sulphuretted hydrogen and carbon dioxide amounts to about 1·2 per cent. Together the SH_2 and CO_2 in the crude gas (excluding any CO_2 which may be drawn in from the furnace) total about 2½ per cent. by volume, thus the ammonia available is theoretically sufficient for removing only about one-half of these impurities. At the outlet of the condensers the impurities in the gas will be present in approximately the following proportions :—

IMPURITIES IN GAS AT OUTLET OF CONDENSERS,

	Grains per 100 cubic feet.	Per cent. by volume (average).
Ammonia	200 to 300	0·75
Sulphuretted hydrogen	600 to 900	1·0
Carbon dioxide	900 to 1,400	1·5
Sulphur compounds	35 to 45	
Hydrocyanic acid	60 to 80	
Naphthalene	20 to 25	

THE ABSORPTION OF CARBON DISULPHIDE

As previously pointed out, water absorbs only about one-thousandth part of its own volume of carbon disulphide ; and, in the usual way, from 2 to 4 grains of this impurity are removed from the gas during its passage through the washers and scrubbers. The reduction of carbon disulphide by treatment with liquor has for long been a subject of investigation, and the extent to which the compound may be absorbed, also the actual chemical manner in which its removal is effected, have given rise to a good deal of discussion. In the first place, it is by no means certain (as is so often stated) that CS_2 is directly absorbed by ammonium sulphide with the formation of ammonium thiocarbonate, according to the equation — $(NH_4)_2S + CS_2 = (NH_4)_2CS_3$ Tilden states that an interaction takes place between carbon disulphide and ammonia whereby a sulphocyanide and sulphide are formed, but heat is necessary for the reaction—$4NH_3 + CS_2 = NH_4CNS + (NH_4)_2S$. The same authority states that combination of the two gases may give rise to ammonium sulphocyanide and thiocarbonate—$4NH_3 + 2CS_2 = NH_4CNS + (NH_4)_2CS_3$. The actual manner in which the CS_2 is removed is, however, not at all clear, and whilst it appears to unite with ammonium sulphide on the lines of the first of the reactions shown above it seems essential that polysulphides or free sulphur should be present; for the two substances do not combine when in the pure state. The carbon dioxide

in the gas, moreover, would have detrimental effects from the point of view of CS_2 removal; for it tends to dissociate ammonium thiocarbonate and to set free the sulphur compound. Some express the opinion that ammonium polysulphide is alone the agent by means of which the CS_2 is removed.

Although all attempts at the reduction of sulphur compounds by treatment with liquor have been attended with somewhat erratic results, there seems little doubt that some appreciable reduction may be effected by dealing with the gas whilst in its hot state. One method of treatment is thoroughly to wash the gas with hot liquor in the hydraulic main, the liquor being circulated and recirculated so that only the surplus flows away. Lunge states that the liquor from the hydraulic main is especially suited for wet purification, for it contains some considerable quantities of free ammonia (*i.e.* NH_3) owing to the far-going dissociation of the "free" salts—carbonate and sulphide. It is probable, therefore, that some absorption of CS_2 may take place owing to the presence of uncombined ammonia in the liquor, and after the manner of Tilden's equations already referred to. No great reliance can, however, be placed in the method. It has, in consequence, not been generally undertaken on gasworks.

So far as the difference of constitution of the liquor from the hydraulic main and of the final product obtained in the storage well is concerned, Meyer and Hempel have given the following interesting table:—

	Liquor from Storage Well.	Liquor from Hydraulic Main.
Total ammonia	1200·6 grains per gallon	405·7 grains per gallon
"Free" „	984·5 „ „ „	204·1 „ „ „
"Fixed" „	216·1 „ „ „	201·6 „ „ „
Ammonium carbonate . . .	2468 grains per gallon	332 grains per gallon
„ sulphide . . .	193 „ „ „	51 „ „ „
„ thiosulphate . .	86 „ „ „	30 „ „ „
„ sulphite . . .	Traces	Nil
„ sulphate . . .	16 „ „ „	16 „ „ „
„ chloride . . .	517 „ „ „	505 „ „ „
„ sulphocyanide .	127 „ „ „	70 „ „ „
„ ferrocyanide . .	6·2 „ „ „	2·3 „ „ „
„ cyanide . . .	8·3 „ „ „	2·4 „ „ „
Uncombined ammonia. . .	7·4 „ „ „	73·0 „ „ „

METHODS OF OPERATING WET PURIFICATION PLANT

The most efficient manner of operating washers and scrubbers is to ensure that the gas on first entering the apparatus is treated with the strongest liquor obtainable, whilst in each subsequent vessel the liquor circulated becomes gradually weaker until, in the final scrubber, clean water is employed. Where circumstances permit it is preferable that the decarbonating vessel be worked with hydraulic main liquor,

as this contains a large proportion of uncombined ammonia, available for the removal of CO_2 and SH_2. Considerable care should be taken in order to prevent the passage forward of tar to the ammonia washers. At the inlet to the washing plant this impurity should be reduced to as low as 2 grains per 100 cubic feet of gas. Davidson has said that the crude gas in the hydraulic main contains as much as 8,000 grains of tar per 100 cubic feet.

The effect of submitting the gas to clean water in the final scrubber is to remove practically the last traces of ammonia from the gas, whilst the water is converted into a weak liquor (from 1 to 2 oz. strength), which, mixed with that flowing from the condensers and hydraulic mains, is passed down the previous portions of apparatus and finally worked up to the desired strength. Herring says that the weak liquor has a slightly greater affinity for the sulphuretted hydrogen, but as its strength increases the carbon dioxide exerts its superior affinity, actively combines with the free ammonia, and breaks up some of the already formed sulphide, giving, instead, ammonium carbonate. Thus in certain of the washing vessels evolution of sulphuretted hydrogen may occur.

As regards the amount of water (other than that formed from the distillation of the coal) which is necessary in order to effect the wet purification of gas, the author finds that with Durham coal the flow through the final scrubber amounts to from 10 to 13 gallons per ton of coal carbonized. With this quantity the ammonia in the outlet gas is reduced to 0·5 grains per 100 cubic feet. Some years ago it was considered that the water required for complete removal of ammonia should be 3 gallons per ton of coal used; but much must depend upon the nature of the coal, the systems of carbonization and condensation, and the type of scrubber in use.

WASHING AND SCRUBBING APPARATUS

The arrangement of the wet purification plant conforms to no regular rules, so that the apparatus and the method of working it vary considerably, in accordance with the tastes of the engineer. Formerly, the removal of ammonia was effected by the use of no other power than the pressure of the gas itself; but, recently, mechanical devices, necessitating the use of external driving power, have come into very general favour. The latter apparatus is commonly known as the washer-scrubber, owing to its ability—due to increased efficiency—to perform the greater portion of the work of these two vessels.

Washing plant may be taken to embrace those portions of the apparatus in which the gas is actually caused to bubble through seals or to pass through weirs of liquor. In scrubbing plant, on the other hand, the gas comes in contact with a wetted surface of coke, boards, or other suitable material. In the design of the washer, the depth of the seals employed, or the resistance offered (and, accordingly, the effectiveness of the machine for removing ammonia) must be balanced against the back-pressure thrown, and in no case should the latter exceed 3 inches for a single machine. Washers are invariably operated with liquor of the maximum strength, whereas in the scrubbers, liquor of a weaker quality is circulated.

To-day, the washer introducing the principle of wire-drawing and bubbling has come into very general use, for not only is such apparatus efficient from the point of view of the removal of the gaseous impurities, but it provides an admirable means of eliminating tar where this may have travelled forward to the wet plant. There are numerous types of this style of washer, but probably the most noteworthy is that designed by the late Sir George Livesey, and employed extensively throughout

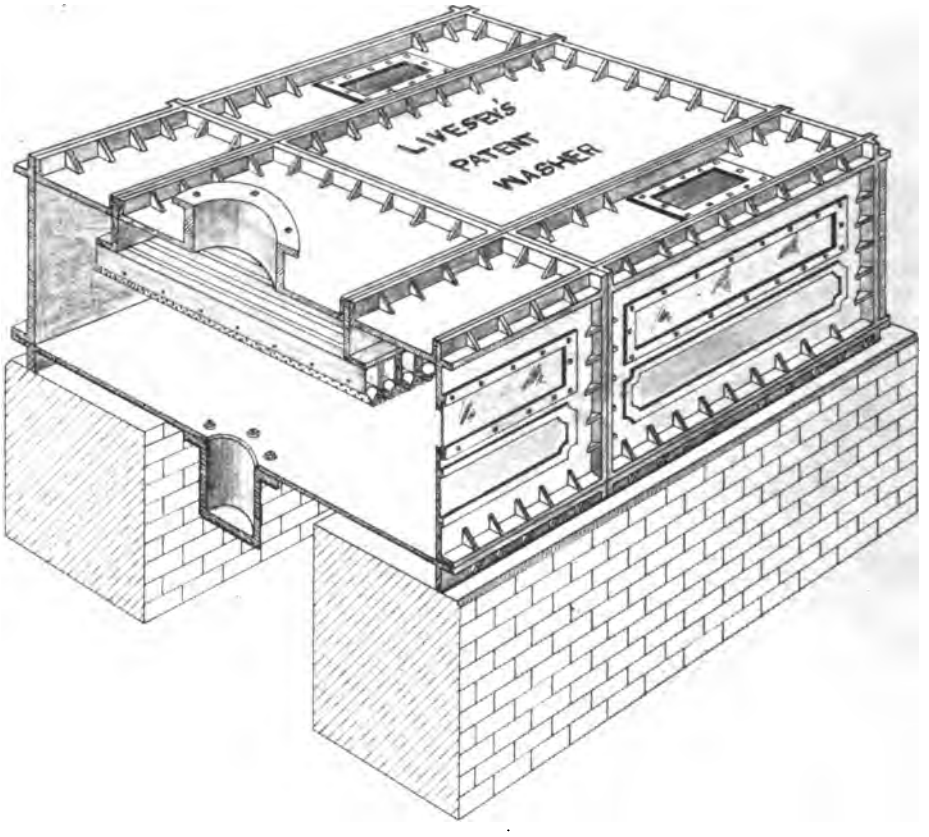


FIG. 224.—THE LIVESEY WASHER.

the world. The apparatus is shown in Fig. 224. It consists of a rectangular cast-iron outer case, the upper portion of which forms an inlet chamber. To the lower flanges of the inlet chamber is fastened a series of wrought-iron pear-shaped tubes, an enlarged section of which is shown in Fig. 225. It will be noticed that whereas the space between these tubes is in communication with the inlet chamber, the interior of the tubes is connected with the outlet chamber. Thus the gas has free access to the intermediate spaces, passes downwards through them, and depresses

the liquid until it (the gas) finds an outlet through the perforations in the bent plate and thence upwards into the space above the plate, whence it travels to the outlet chamber. The bubbles of gas in passing through the liquor into the tube space convert the surface into a foam, thus the most thorough contact of gas and liquor is assured. In order to prevent the gas passing direct from the inlet to the outlet chamber the ends of the intermediate spaces are securely closed up. The perforations in the tubes are usually one-twentieth of an inch in diameter, and so placed that there are about thirty to the square inch. The washer will be found to work most effectively when the depth of liquor is such that it rises to an inch above the top of the pear-shaped plates, in which case 3 inches of pressure is thrown.

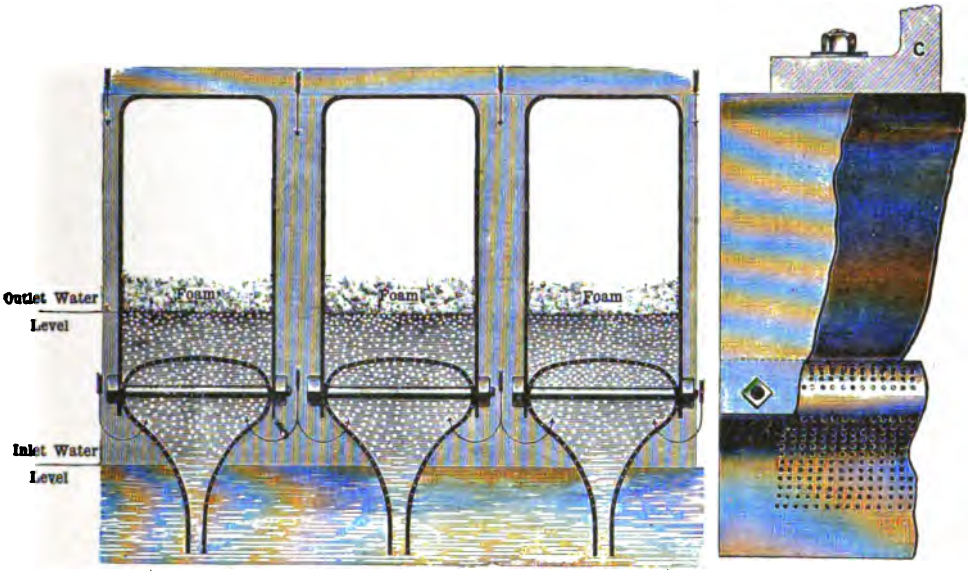


FIG. 225.—LIVESEY WASHER, DETAIL OF PERFORATED PLATES.

There are now many washers in use which are operated on the bubbling and wire-drawing principle; and from the point of view of tar extraction efficiency the type is probably not to be excelled. Cockey's washer is shown in Fig. 226. It consists of a cast-iron vessel divided off by horizontal partitions into three or more chambers. The gas entering at the base travels upwards through a vertical pipe to the top of which is fitted a hood. The gas meets the hood and is then deflected downwards through four openings in the horizontal plate and passes through the liquor. It then travels past several serrated edges which are sealed in liquor, and afterwards finds its way to the next chamber. The liquor flows from the top chamber downwards; and the depth of the seals may be regulated as desired.

Dempster's washer is shown in Fig. 227. It is composed of a number of cast-iron trays placed one above the other, the trays having a number of narrow openings, with raised edges. These openings are covered with hoods having serrated edges,

and each tray contains liquor in which the serrations of these hoods are sealed. The weaker liquor enters at the top and flows round the hoods, as shown in the

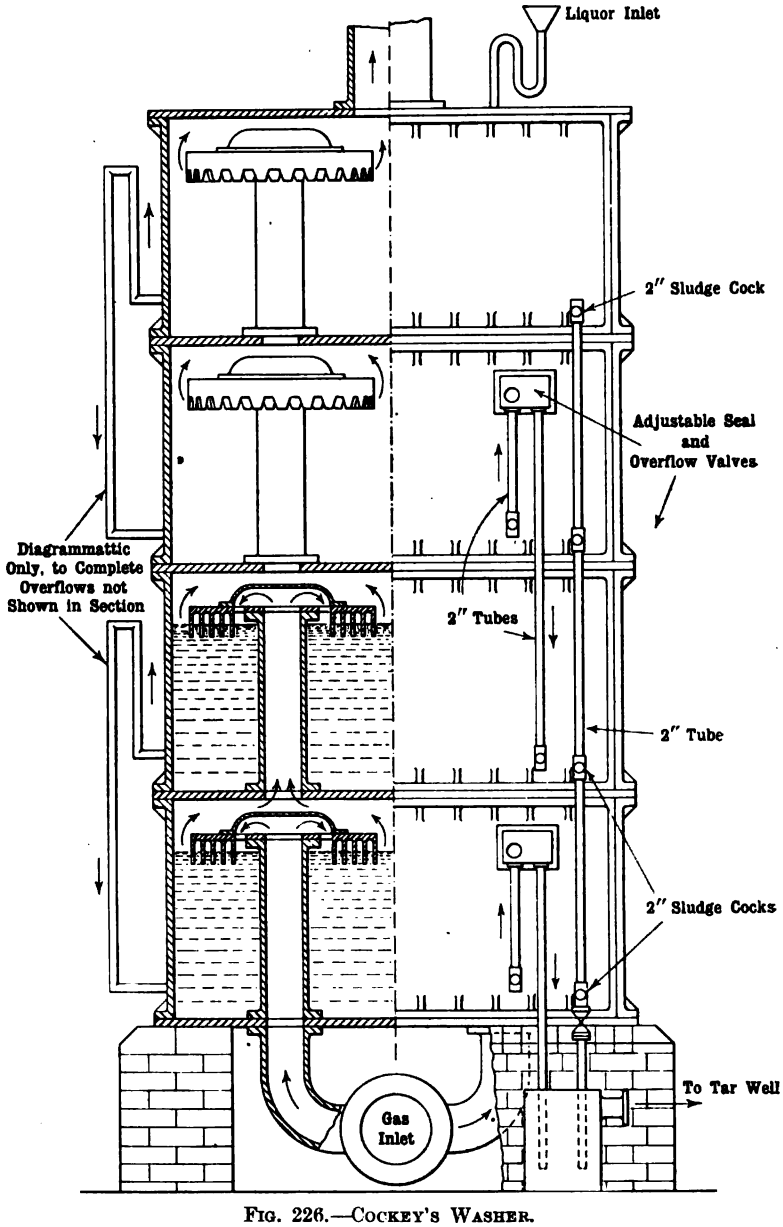


FIG. 226.—COCKEY'S WASHER.

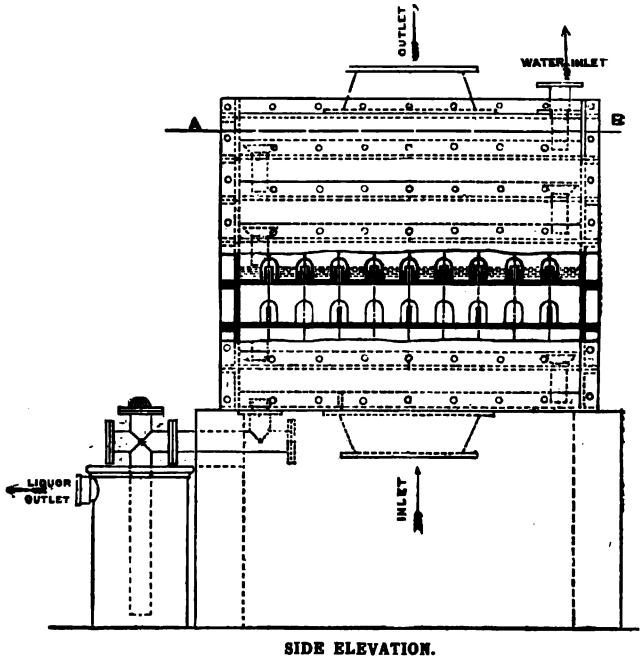
sectional plan, thence overflows to the section below, and finally is drawn off at the base of the vessel. The gas enters at the bottom and passes upwards through the

openings in the bottom tray and through the liquor sealed serrations of the hoods until it passes to the outlet at the top.

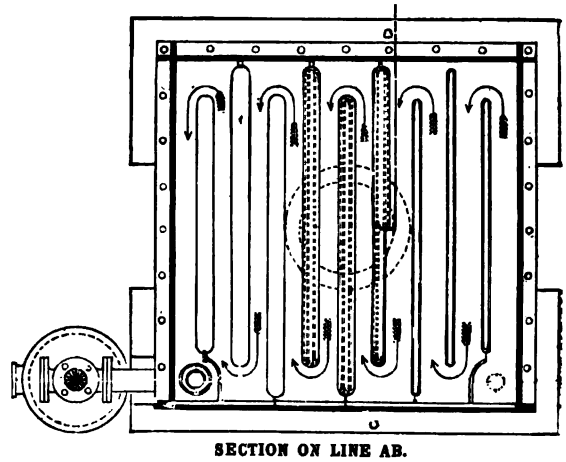
A washer hailing from America is known as the "Multiple" and is shown in Fig. 228. It is designed on lines very similar to the Livesey type, horizontal inverted U-section troughs being used for breaking up the gas. To the lower edges of each U-trough three perforated plates, set out at a wide angle, are attached. The plates are set one above the other, but are so arranged that the distance they project decreases from the topmost downward. The perforations in these plates decrease in diameter and increase in size from the bottom upwards, whilst their edges are serrated.

The principle of Walker's washer is shown in Fig. 229. The gas from the inlet pipe enters a central chamber, branching away from which are a number of longitudinal troughs, open at the bottom but closed at the far end. The level of the liquor in the cast-iron external shell is such that the lower ends of the troughs are sealed,

FIG. 228.—THE "MULTIPLE" WASHER.



SIDE ELEVATION.



SECTION ON LINE AB.

FIG. 227.—DEMPSTER'S WASHER.

and whilst the bottom edges are perforated there are a number of narrow slots in the side of the troughs through which the bulk of the gas passes. In general, the washer forms a distinct piece of apparatus; but, if desired, it may be fitted in the base of a scrubber, as seen in Fig. 241 (page 350).

In some cases the functions of tar-extracting, washing and scrubbing are merged into one vessel, known as a purifying machine. In the Walker apparatus (Fig. 230) the gas is first treated in the lower portion of the vessel, which contains a washer similar to that shown in Fig. 229. It then travels upwards to the next compartment,

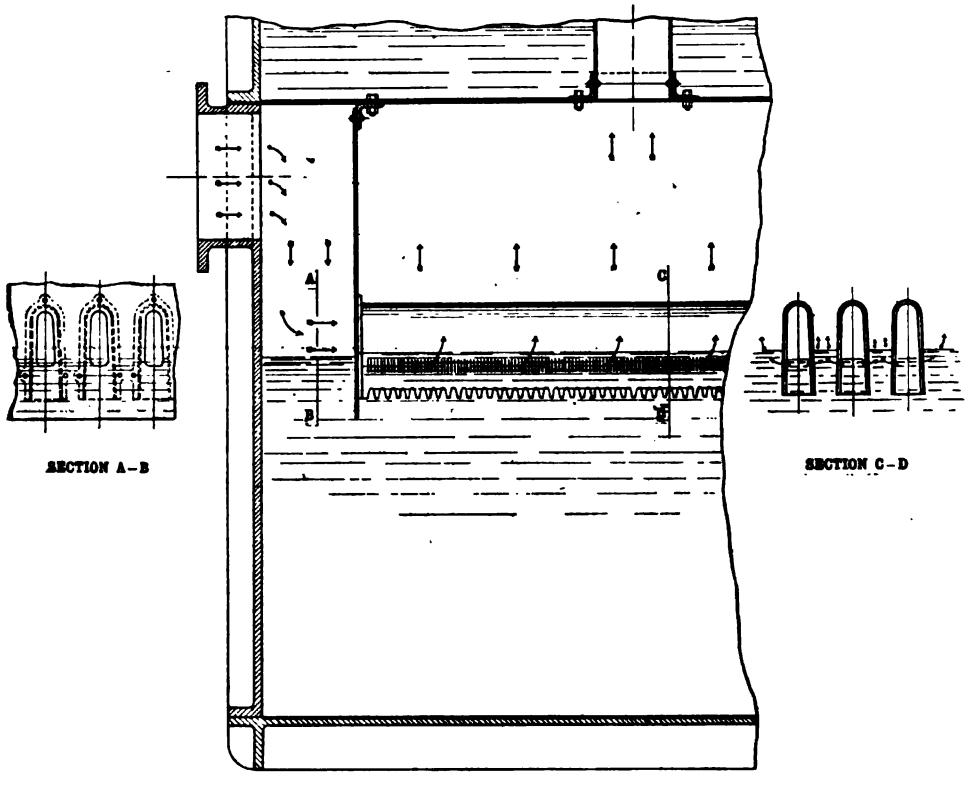


FIG. 229.—WALKER'S WASHER.

where it comes in contact with strong liquor distributed over devices containing wetted boards. The gas then travels through a number of superimposed tiers of such boards and is taken off at the top of the machine. A vertical shaft passes through the centre of each of the boxes containing the boards, the ends of the shaft being connected to rocking levers carried from pivots on the top of the machine. The rocking levers are operated by a small engine placed at ground level, and by means of these levers the boxes are raised and lowered about every ten seconds. The boards contained in the boxes are, in this way, frequently immersed in the liquor contained

in their respective compartments, and are then exposed in their wet condition to the crude gas. Effective contact with a large area of wetted surface is thus ensured. Clean water is admitted to the top of the machine at the rate of 10 gallons per ton of coal carbonized, and flows out at the base as a liquor of from 16 to 22 oz. strength. The back-pressure thrown by the apparatus is extremely small, amounting to little more than 1 inch of water.

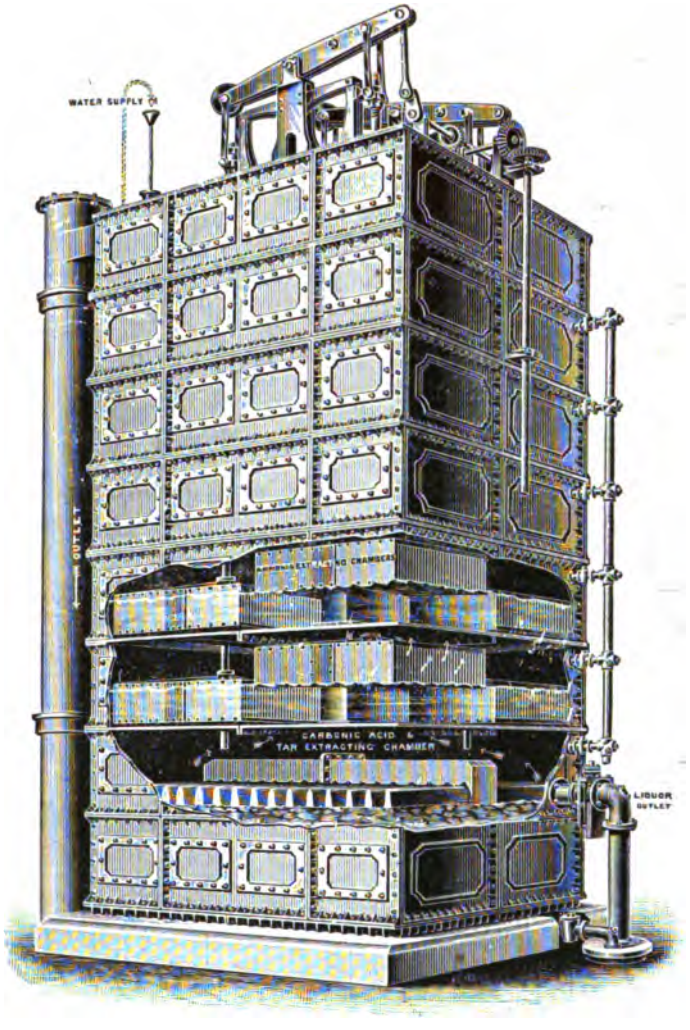


FIG. 230.—WALKER'S PURIFYING MACHINE.

MECHANICAL WASHER-SCRUBBERS

Plant of this description has been introduced with a view to combining the functions of the washers and scrubbers. On the majority of the larger works some apparatus of the kind is now to be found. The increased efficiency of ammonia extraction obtained is largely dependent upon the large area of freshly wetted surface with which the gas is brought in contact, also the "breaking-up" effect of the mechanically operated portions. The primary objection to machines of this type is the necessity for employing motive power, whilst the introduction of running parts accounts for some expenditure on wear and tear. At the same time, the capacity of the machines for dealing with a definite quantity of gas is considerably less than that necessary with the ordinary type of washing and scrubbing plant; thus, when a large stream of gas is to be treated, substantial saving in capital outlay will be effected by the employment of the washer-scrubber. There are several

types of washer-scrubber now in use, but in many cases a strong resemblance is shown. Essentially, the machines consist of a series of cylindrical bays, made from cast-iron, and bolted together so as to form a number of compartments. A rotating shaft carrying some form of agitating gear runs through the centre of the cylinder. The crude gas entering at one end passes out at the further end of the cylinder deprived of the greater portion of its ammonia, while clean water (flowing in at the opposite end to the gas) travels from bay to bay, being converted into a liquor of gradually increasing strength. In the most effective machines, clean water running into the final bay will be worked up to a liquor of about 12 oz. strength by the time it reaches the opposite end of the cylinder.

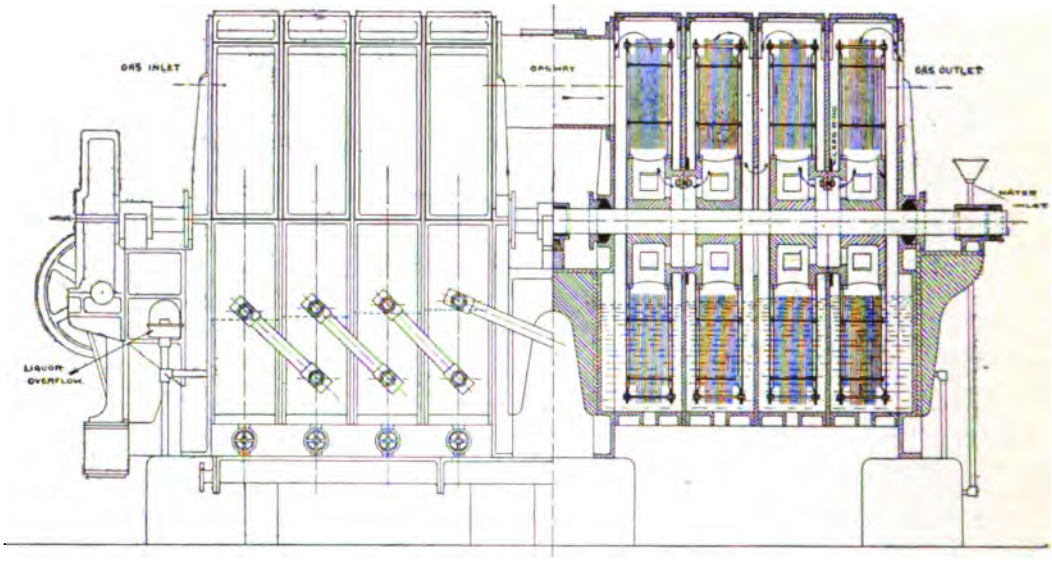


FIG. 231.—KIRKHAM, HULETT AND CHANDLER'S "STANDARD" WASHER-SCRUBBER.

Washer-scrubbers may be classified into two distinct groups :—

(*a*) Horizontal types.

(*b*) Vertical centrifugal types.

Type (*a*) was introduced many years ago by Paddon, and although it is still very much in evidence on gasworks, there is some tendency for the more effective centrifugal type to take its place. Of type (*a*) the original machine of Kirkham, Hulett and Chandler (Fig. 231) is, perhaps, the best known. In its latest and improved form it consists of a number of concentric cast-iron rings bolted together and divided into separate compartments by means of circular division plates having openings in the centre to permit of the passage of the gas. The machine is constructed in two sections with intermediate bearings at the centre, whilst a connecting main from section to section is provided for the passage of the gas. In the original machine the central shaft was carried on bearings inside the washing chambers,

which rendered the bearings extremely difficult of access, and frequently resulted in the fracture of the shaft. The washing appliance consists of bundles of corrugated wrought-iron sheets, the corrugations of alternate sheets crossing one another diagonally. The bundles (Fig. 232) are attached together so as to form a complete circle, and are fixed to the central shaft by means of double collars. The collars are made of such a size as to obstruct the direct passage of the gas from bay to bay and to cause it to take a circuitous path in contact with the wetted bundles. In order to preclude still further the possibility of "slip" a special arrangement of lead rings is fitted so as to bear upon the collar and completely close any gas way

FIG. 232.—CORRUGATED-IRON BUNDLE FOR "STANDARD" MACHINE.

except through the bundles. The arrangement is clearly seen in Fig. 232. The liquor flows from bay to bay by means of the external sloping pipes shown, its usual depth being rather less than one-third of the diameter of the machine. When the machine is used for cyanide extraction the corrugated iron bundles are replaced by a somewhat similar pattern made from wood.

The Whessoe washer-scrubber (Fig. 233) is very similar in construction to that described above, and is, in fact, worked on the same lines as the Kirkham and Chandler machine. Wooden bundles are used, and the machine is divided into four sections and driven from the centre of the shaft instead of from one end.

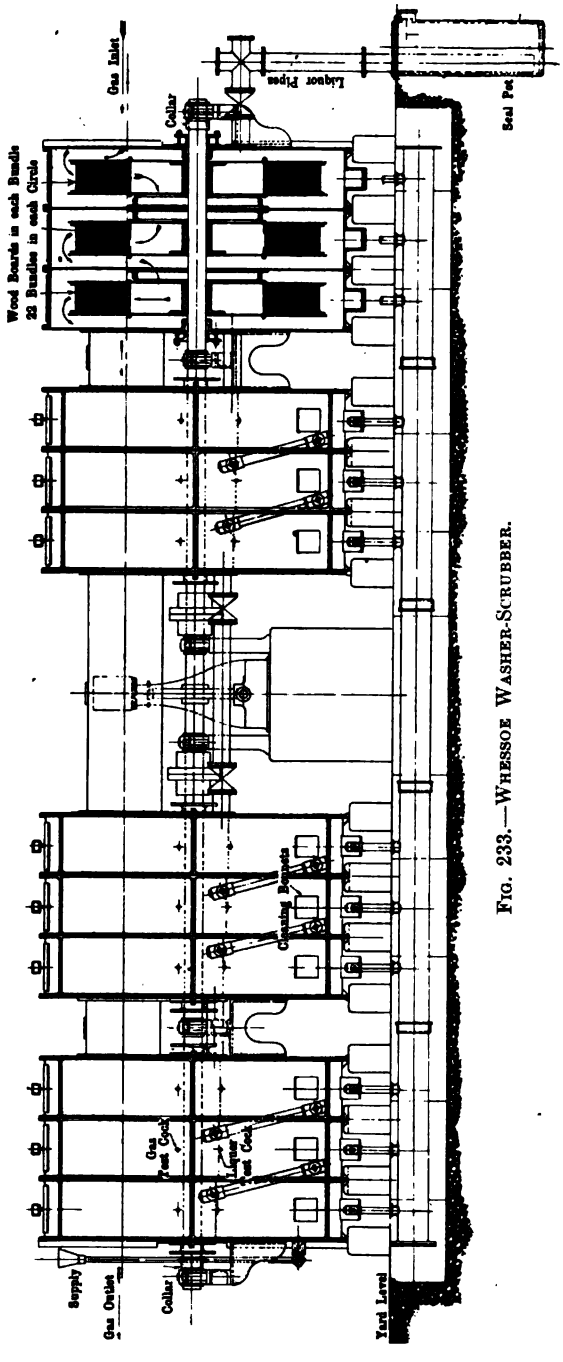


FIG. 233.—WHESSOE WASHER-SCRUBBER.

Holmes' washer-scrubber is now made in two sections, as shown in Fig. 234, and is so arranged that either the whole or only one-half of the machine may be used at one time. In its later form it is driven from the centre of the shaft, and by withdrawing the coupling bolts one-half of the shaft only is revolved. The scrubbing appliance differs from that in other machines in that it consists of a number of brushes made from foreign bass and attached to a framework carried from the central shaft. The gas in passing from bay to bay finds a path between the bristles of the brushes and is, accordingly, subjected to most intimate contact with the liquor.

Clapham's "Eclipse" washer-scrubber was one of the first to be introduced and is still in common use, although some modification has taken place as compared with the original machines. It is particularly of interest in view of the unique means employed for bringing the crude gas in contact with wetted surfaces. The outer case is not cylindrical, the lower portion being rectangular and the upper half semi-circular. The shell, as in other machines, is divided into a number of compartments in which cylindrical cases (made from cast iron) and having perforated back and front plates, revolve. These cases, which vary in number from 8 to 12, contain several compartments, all of which are filled with wooden balls. The

balls are kept in position in the cases by means of sheet-iron cover plates arranged round the periphery. The balls vary from 1¼ inches to 2 inches in diameter, according to the size of the machine. They are made from hard sycamore, and each has a hole, half-an-inch in diameter, bored through the centre. The machine is so arranged that the gas is caused to travel in contact with the balls, and thus becomes thoroughly subjected to the action of the liquor. In some cases a series of perforated buckets have been fixed upon the cases, and so arranged that they pick up the liquor and discharge it over the balls when at the top of their circular course.

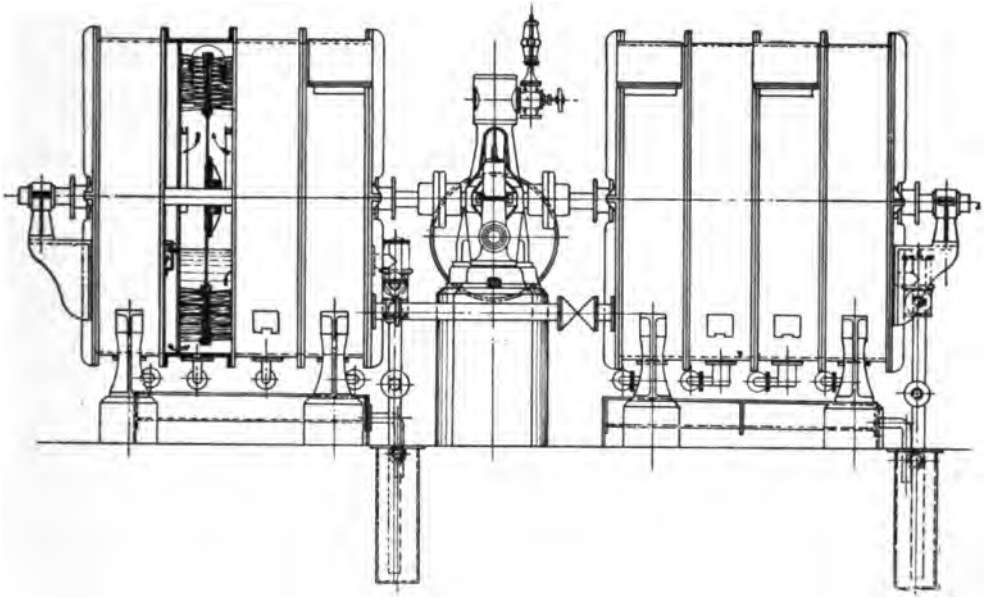


FIG. 234.—HOLMES' WASHER-SCRUBBER.

CENTRIFUGAL WASHER-SCRUBBERS

Centrifugal washer-scrubbers are of comparatively recent introduction, and differ considerably from the machines previously described. First, they are essentially of the vertical type, having a series of vertical compartments through which the gas passes in sequence. The best known in this country is that made by Kirkham, Hulett and Chandler, illustrated in Fig. 236. It consists of a cylindrical cast-iron vessel divided into a number of chambers through which passes a vertical shaft. To this shaft are attached specially shaped trays, which, revolving at a speed of about 100 to 150 revolutions per minute, lift up and spray the washing liquid so as to bring it into intimate contact with the ascending stream of gas. The number of chambers varies from two to ten, according to the purpose for which the apparatus is required; but, in general, the machines composed of a small num-

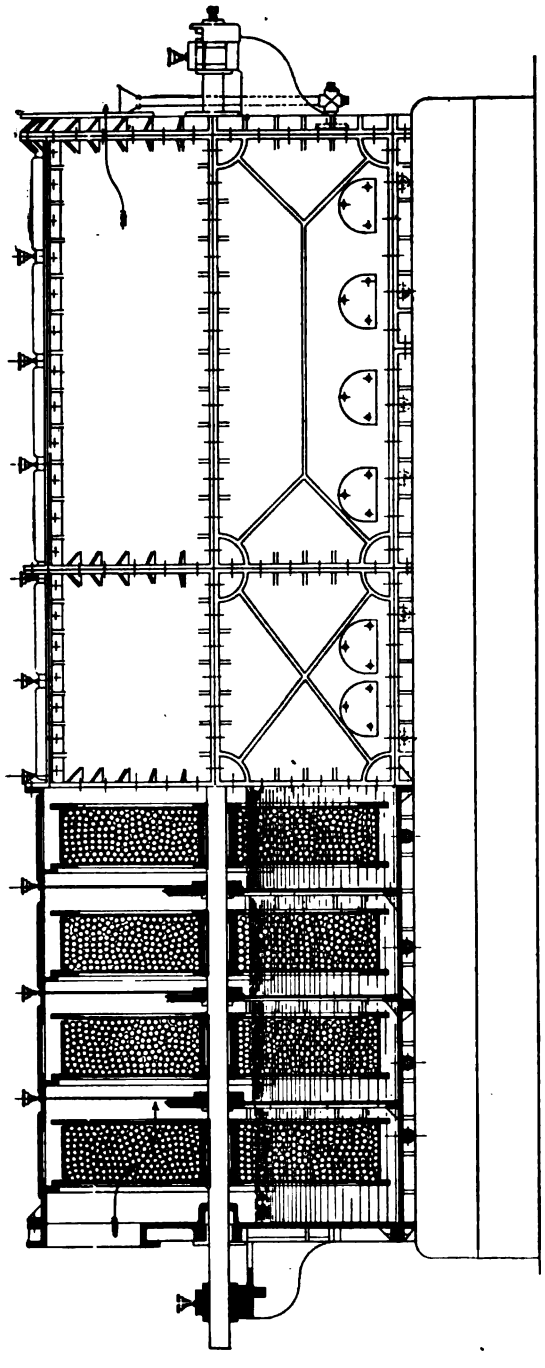


Fig. 235.—Clapham's Eclipse Washer-Scrubber.

ber of chambers are employed for naphthalene washing, spraying an oil instead of gas liquor. The construction of the trays is best seen from Fig. 237. Each tray is composed of a perforated rim, whilst depending from the bottom are four bent tubes, the sides of which are also perforated. As the shaft revolves the liquid is forced up the bent tubes into the trays, whence it is flung by centrifugal force across the gas space, rebounding again from the outer walls of the cylinder, and once more coming in contact with the gas. The gas is admitted into the lowest washing chamber, passes through the spray to the central opening in the bottom of the second chamber, thence through the second spray, and so on into the third and subsequent chambers. The washing medium is admitted at the top of the vessel, flows through the centre openings from chamber to chamber, and is finally run off at the bottom. In an eight-chamber machine clean water admitted at the top will be discharged as 16 oz. liquor, and—if so desired—the last traces of ammonia may be removed. This washer is equally suitable for the extraction of cyanogen from the gas. When used for this purpose the sprayers are made entirely of cast iron. For naphthalene removal the machine is constructed of from

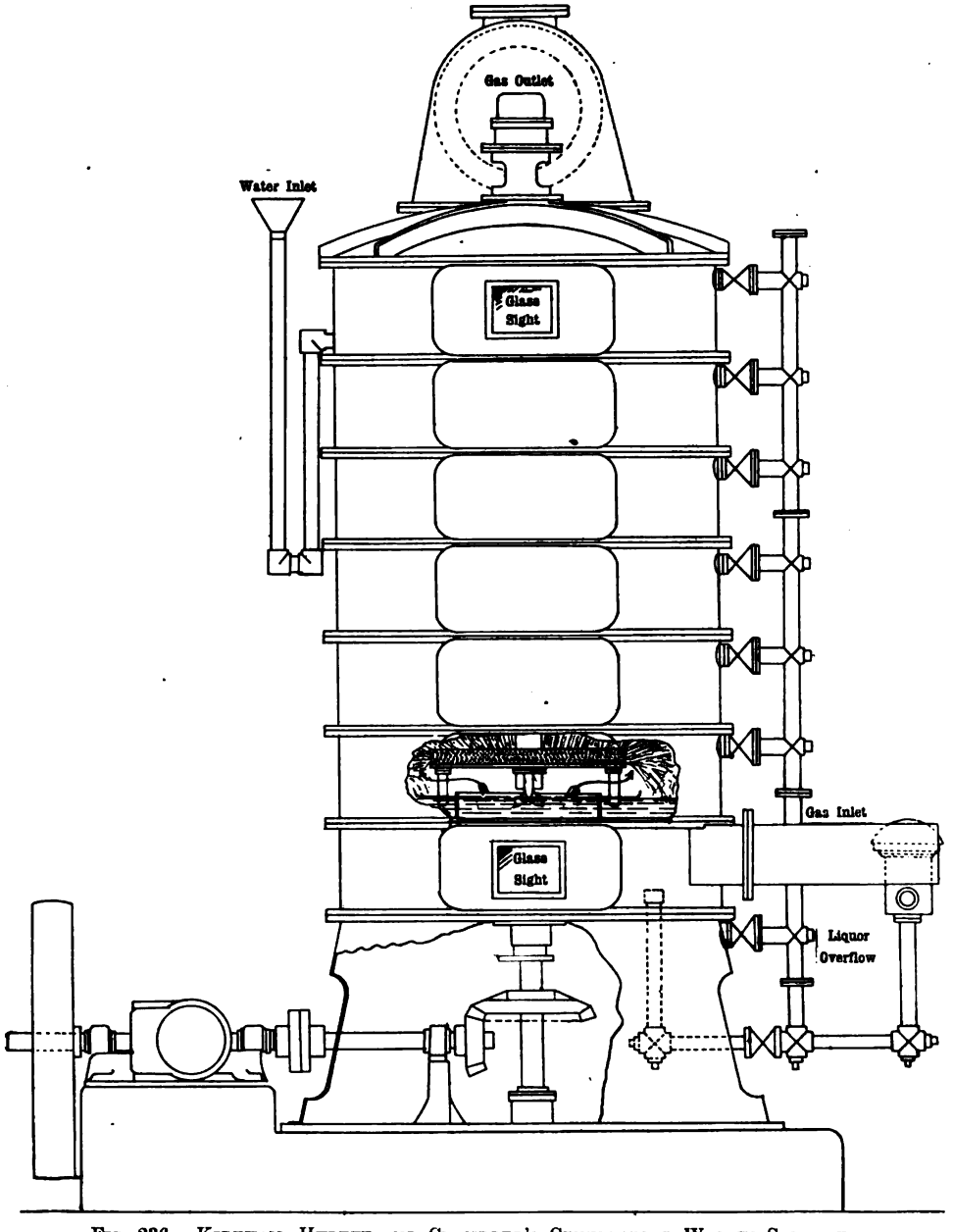


FIG. 236.—KIRKHAM, HULETT AND CHANDLER'S CENTRIFUGAL WASHER-SCRUBBER.

2 to 6 chambers, but one machine may be used for both purposes, arrangements being made so that one or two chambers are supplied with water gas tar or other solvent whilst the remainder are operated with liquor. The upper chambers

should preferably be used for naphthalene removal, and the lower ones for ammonia extraction.

The Dempster-Feld washer (Fig. 238) is similar to that described above in so far as it consists of a number of superimposed chambers, through which passes a vertical shaft rotating at a speed of about 120 revolutions per minute. The spraying device, which is similar in all chambers, and is shown in detail in Fig. 239, is composed of a number of cones, varying from six to twelve, attached to the shaft by means of a cast-iron hub. The lower ends of the cones are so arranged that they dip into the liquor contained in the dish-shaped channel in the base of the chambers. As the shaft rotates, the water is drawn up through the spaces between the cones, and is thrown off at a tangent at the upper edge with tremendous velocity, and passes across the gas space. The base of each compartment is provided with four apertures through which the gas travels from chamber to chamber, entering at the base and leaving

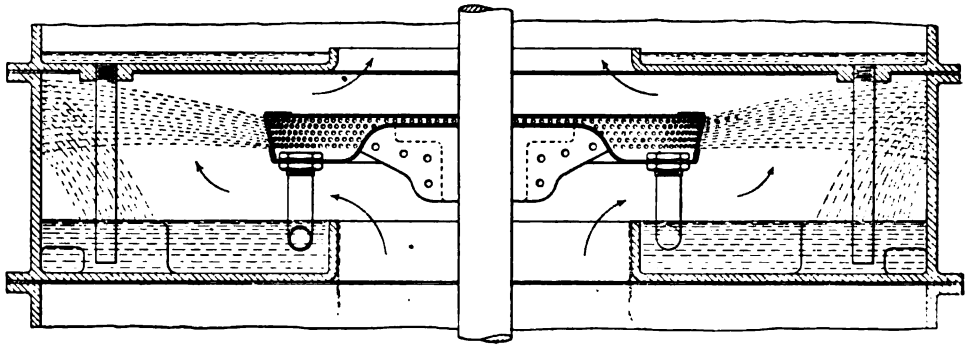


FIG. 237.—CENTRIFUGAL WASHER-SCRUBBER. DETAIL OF SPRAYING DEVICE.

at the apex. A machine dealing with 3 million cubic feet per day is only 5 feet in diameter and 23 feet high over all, which includes the height of the pier on which the machine stands. A baffle plate is fixed in the outlet compartment of the washer, which ensures the gas passing away in a dry state. The washers are made in sizes varying from 250,000 to 45,000,000 cubic feet of gas per 24 hours.

HORSE POWER REQUIRED BY WASHER-SCRUBBERS

The power required to drive washer-scrubbers depends upon the size of scrubbers, the speed of running, and the washing medium employed, *i.e.* weak or strong liquor, tar or oil. Speed for speed the horizontal types absorb the larger amount of power, but owing to the very much greater rate at which the vertical machines travel they are usually rather more extravagant in this direction. The following figures (relating to the Kirkham, Hulett and Chandler washers) show the approxi-

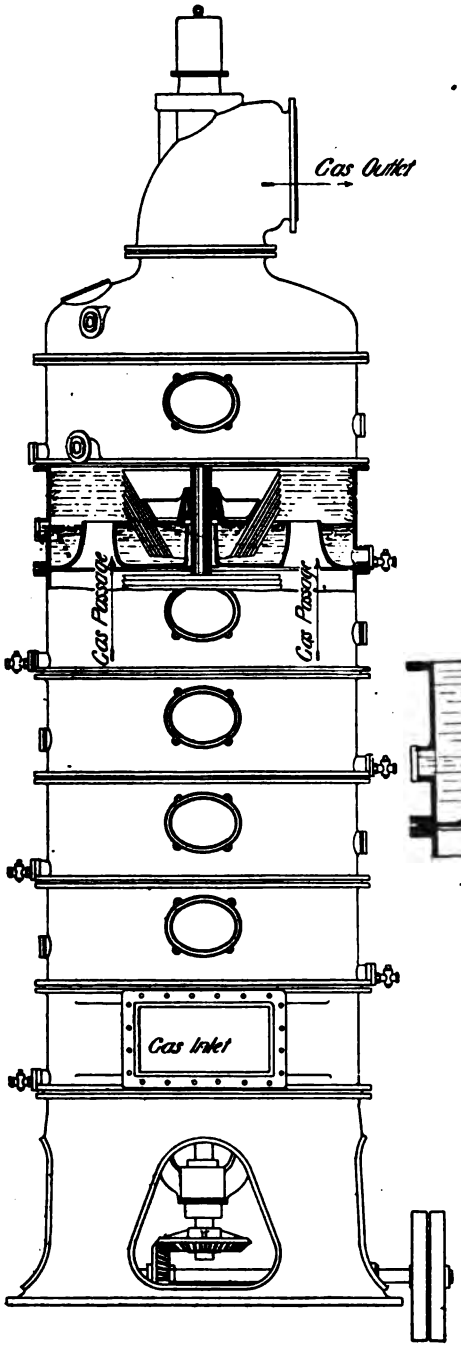


FIG. 238.—THE DEMPSTER-FELD CENTRIFUGAL WASHER.

mate powers required for various sizes of machines; but when installing driving plant for this purpose it is advisable to allow some further margin (say 20 per cent.) for contingencies :—

Cubic feet.	Horizontal.	Vertical.
500,000 per diem	3 h.p.	4 h.p.
1,000,000 „ „	4 h.p.	5 h.p.
2,000,000 „ „	5 h.p.	7 h.p.
3,000,000 „ „	6 h.p.	10 h.p.

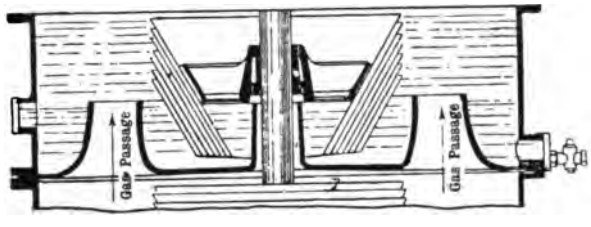


FIG. 239.—DEMPSTER-FELD WASHER SPRAYING CONES.

From this it will be seen that if electrical energy is used the cost per day for driving a 3 million cubic feet vertical machine would amount to 8*s*., or about ·033*d*. per 1,000 cubic feet of gas treated, or 0·4*d*. per ton of coal, with electricity at a halfpenny per unit.

SCRUBBERS

Scrubbers of some form or other are almost universally employed for removing the last traces of ammonia from coal gas. They consist of either rectangular or cylindrical vessels, the height of which is comparatively great in relation to the width or diameter. The ratio of height to diameter usually varies between 2½ and 5 to 1, although in some instances it may be as much as 7 to 1, particularly in the case of scrubbers of comparatively small capacity. The cylindrical section is nearly always adopted, and the majority of scrubbers are constructed from cast-iron plates bolted together so as to form tiers. At the bottom of each tier or bay a grid is fixed to brackets cast on to the side plates whilst the gas outlet pipe, in many forms, passes down the centre of the vessel. Steel has been employed to some extent in the construction of scrubbers, the ring sections being riveted up by lap or butt joints, with external angles at the top and bottom of the sheet. Owing to its superior endurance against corrosion cast iron is, however, still preferred

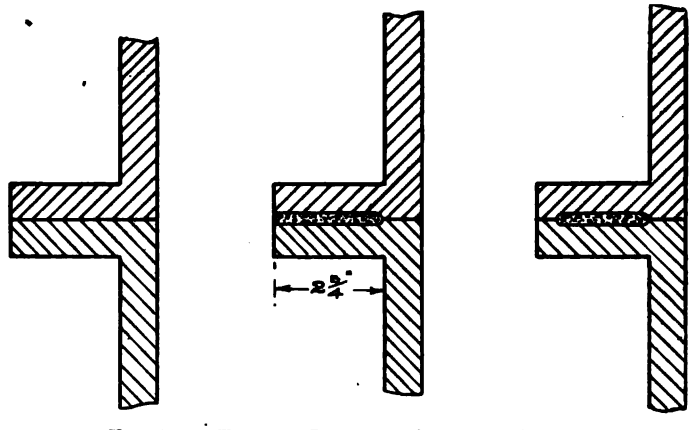


FIG. 240.—TYPICAL JOINTS IN CAST-IRON WORK.

by many engineers. Cast iron possesses, moreover, a secondary advantage in that the vessel is easily taken to pieces, and may be sold and re-erected elsewhere when it may have been outgrown by the increased output of the works.

In cast-iron work, as in common use for the construction of scrubbers, washers, tanks, purifiers, etc., three types of joint are found. These are shown in Fig. 240. It must be emphasized that although rust joints, composed of iron borings and cement (*see* page 159) are extremely strong they are not altogether desirable when such substances as ammoniacal liquor are being dealt with, so that faced joints should preferably be employed. For smaller scrubbers (say up to 5 feet diameter) the depth of the cast-iron plates is 4 feet, whilst above this size 5 feet plates are used. When the diameter of the scrubber is exceptionally large (over 30 feet) the flat cast-iron top becomes decidedly cumbersome, and is liable to sag. In

such cases it may be advisable to construct a domed top having a rise equal to one-sixth of its diameter and made from steel.

The function of the scrubber is to bring the partly purified gas in contact with large areas of wetted surface, and to this end the tower is packed with various materials which are laid on the grids at the base of each tier of plates. The type of packing required and its disposition have no little influence on the efficiency of the scrubber, hence considerable care should be given to this point. The chief points to be kept in mind when deciding upon the method of packing are the following :—

(1) A large area of exposed surfaces is required.

(2) The surfaces should be rough.

(3) Any tendency for the gas to " slip " must be avoided, and the stream should be broken up as far as possible.

(4) Initial cost of the packing material.

(5) The life of the material.

(6) Ease of cleaning out.

Brushwood and fascines were largely used as a packing in by-gone days, but have now been superseded by layers of coke, wooden blocks, drain-pipes, grids, and boards on edge. As regards the relative areas exposed to the gas by these materials, Livesey has given the following figures :—

Coke	8½	square feet	per	cubic foot	of	scrubber capacity.
Drain-pipes, 3 inch diameter	17	„	„	„	„	„
„ 2 inch „	21	„	„	„	„	„
Boards on edge . .	31	„	„	„	„	„

Dr. Carpenter has obtained extremely high efficiency by packing scrubbers with metal bundles somewhat similar to those employed in Kirkham, Hulett and Chandler's horizontal washer-scrubber (Fig. 231). There is little doubt, however, that, considering efficiency in conjunction with expense, it is difficult to improve on a packing composed of boards placed on edge. These should be rough sawn and arranged in chequer fashion, so as to give a sieve-like construction. The size of boards conforms to no hard and fast rule. The following may, however, be taken as affording satisfactory results :—

6-inch boards, $\frac{1}{4}$ inch thick, laid $\frac{3}{4}$ inch apart.

11-inch boards, $\frac{1}{2}$ inch thick, laid $\frac{1}{2}$ inch to $\frac{3}{4}$ inch apart.

A typical tower scrubber complete with board filling is shown in Fig. 241. In this case the bottom compartment forms a washer for the purpose of tar removal.

Board or grid filling for scrubbers is somewhat costly in the first instance, and where expense is of material importance tiers of coke may be substituted. Approximately, board filling will cost four times more than coke tiers, but it may be made use of over and over again. Whatever type of filling is employed it is essential that the upper surface of each layer should not be in contact with the underside of the grid supporting the layer above it, otherwise irregular distribution of gas and liquor, also increased back-pressure, will result. When the distance between the

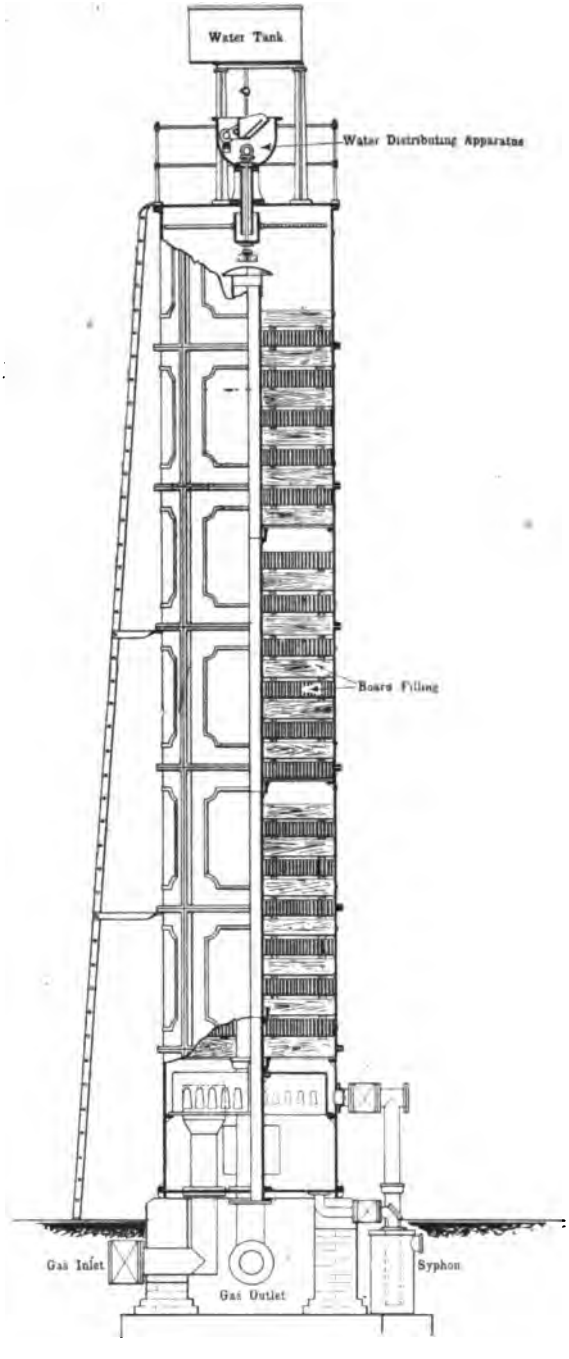


FIG. 241.—TYPICAL TOWER SCRUBBER WITH WASHER AT BASE.

tiers is 5 feet, at least 1 foot of clearance should be allowed, and when 4 feet, 6 to 9 inches is advisable.

Except in small works it is common to find scrubbers erected in pairs, whilst in the largest works there may be batteries of several. Whatever the number, it should always be arranged for the gas to come in contact with clean water before going forward to the purifiers. When two or more scrubbers are in use the last should be supplied with clean water alone, this running out at the base as a weak liquor, which is then pumped up to the preceding scrubber, and so on. When only one scrubber is available it should be so operated that the upper portion is supplied with clean water, whilst the lower tiers are treated with liquor from an intermediate spray.

An effective scheme has been introduced by Thos. Glover, and is illustrated in Fig. 242. The scrubbers are both fitted with boards and are supplied with liquor which is previously passed through a strainer. The second scrubber is supplied with plate-glass windows placed opposite each other, so that if the vessel is carrying out its work effectively it is possible to see clearly through it from side to side. Half-way from the top weak liquor is sprayed on to the boards, whilst the upper half is supplied with clean water alone. The liquor flowing from the scrubbers passes through a

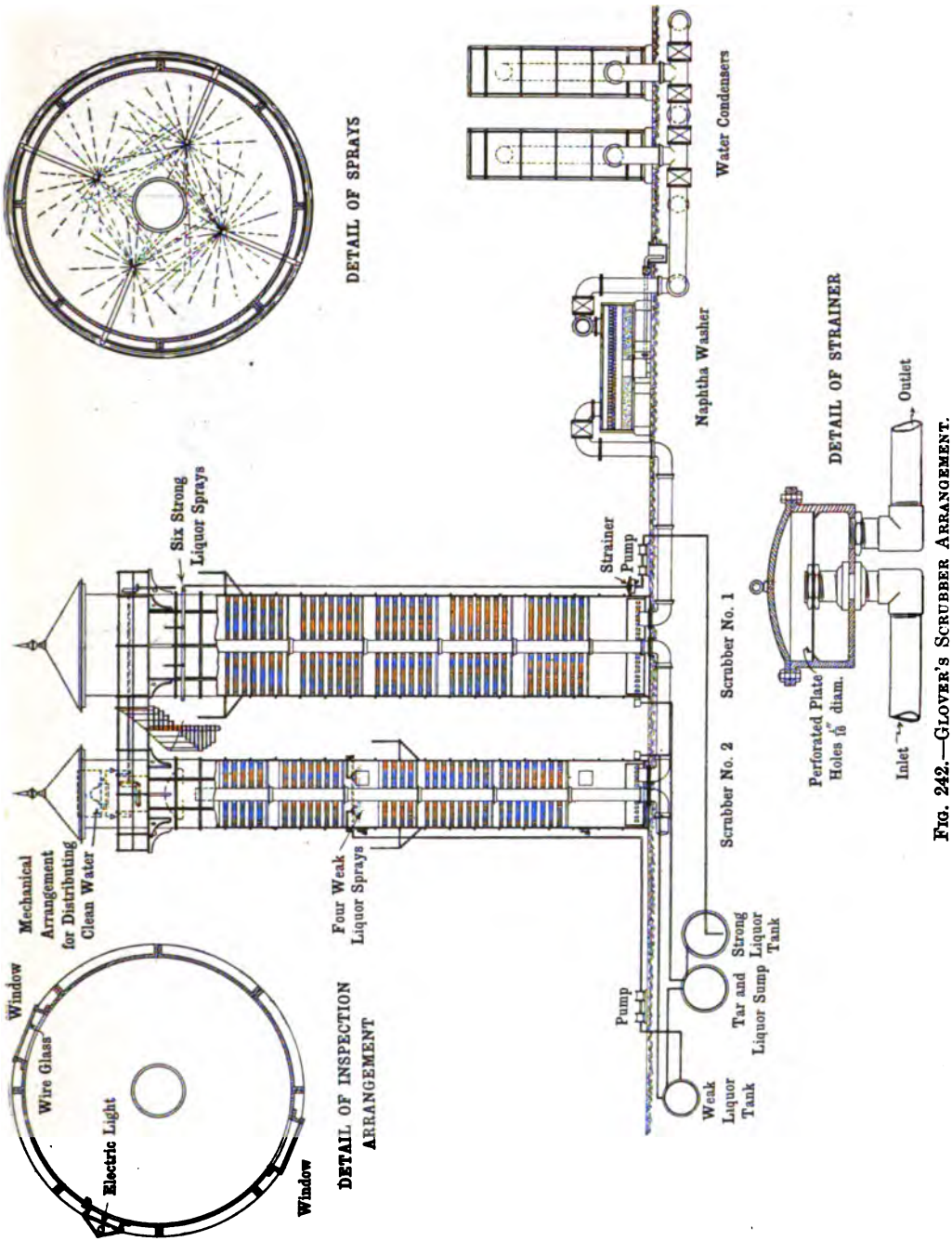


FIG. 242.—GLOVER'S SCRUBBER ARRANGEMENT.

sealed sight overflow. In this way the rate of flow is readily seen and ammonia loss is prevented.

LIQUOR DISTRIBUTORS

There are many types of liquor distributors or sprays now in use, the main object being that of ensuring a regular flow. It is also essential that the scrubbing liquid should be spread over the entire cross-section in uniform quantities,

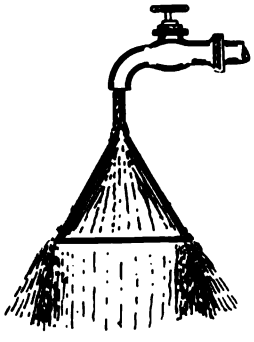


FIG. 243.—INVERTED CONE DISTRIBUTOR.

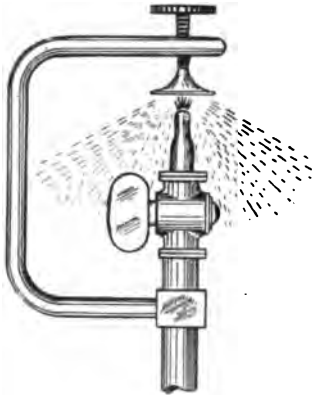


FIG. 244.—GURNEY'S JET.

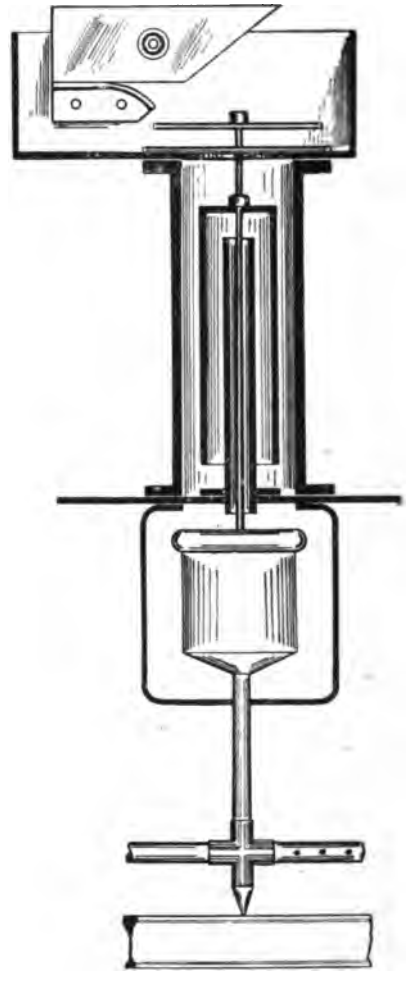


FIG. 245.—BARKER'S MILL OPERATED BY TUMBLER.

and atomized if possible. Liquor distributors may be classified into two sections, namely, those operated under pressure and those in which practically no head of water is available. Modern scrubbers should preferably be fitted with a main pressure box situated in the centre of the top cover plate of the vessel and from which arms radiate in various directions. The pressure of the liquor or water is

then maintained by a suitable pump, and atomizers are spaced at intervals through the cover plate. For small works where no great pressure is available the best results will be given by some simple means such as the inverted cone (Fig. 243) or Gurney's jet (Fig. 244). The well-known principle of the Barker's mill is also very effective, but unless a certain amount of head is available the arms of the mill will remain stationary, with the result that local spraying will occur. On this account it is the general practice to employ the device known as the "tumbler," particularly when the amount of water entering the scrubber is so small as to be little more than a trickle. The sudden discharge of the tumbler, taking place at intervals, creates a certain amount of velocity head, which causes the arms of the mill to rotate for a short period. A complete installation of a tumbler and Barker's mill is shown in Fig. 245. Fig. 246 shows another means of operating the mill without the tumbler, and, consequently, is applicable where a moderately full stream of liquor is available. Fig. 247 shows an arrangement by means of which the sprayer arms, with the aid of suitable gearing, are revolved by a water wheel. Some engineers prefer to arrange for an intermittent flush

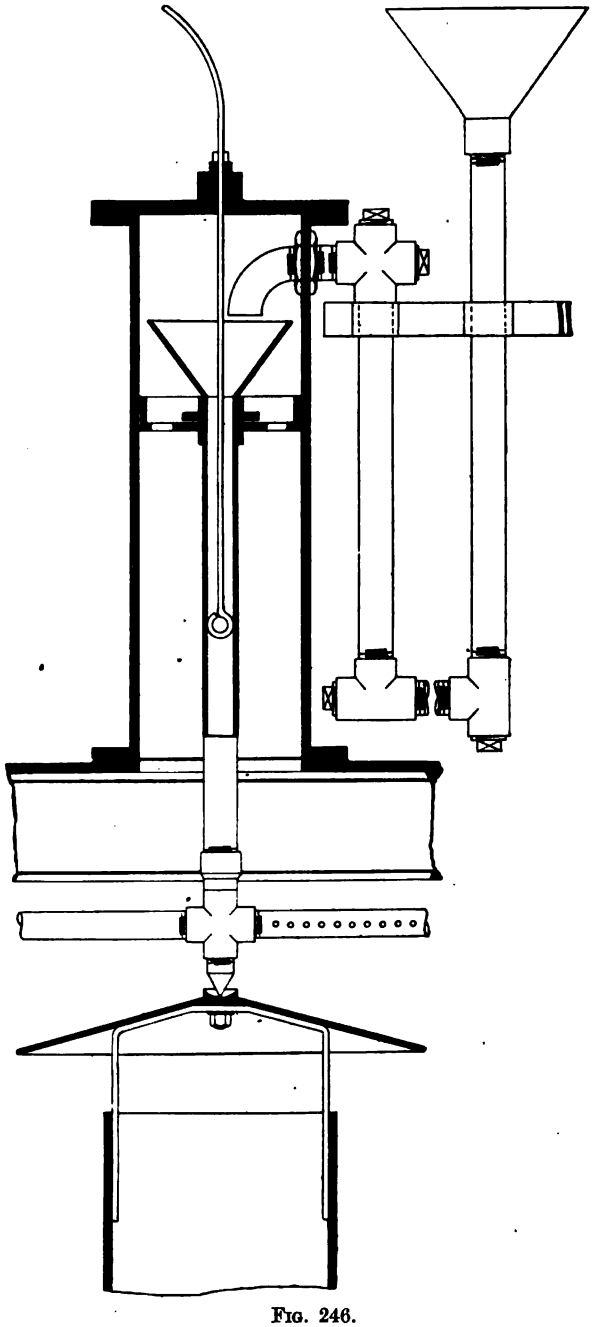


FIG. 246.

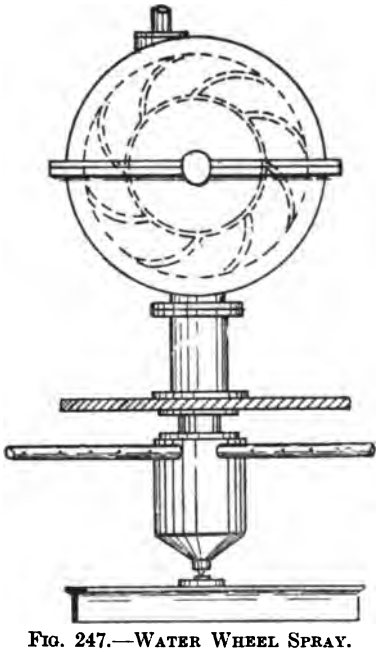


FIG. 247.—WATER WHEEL SPRAY.

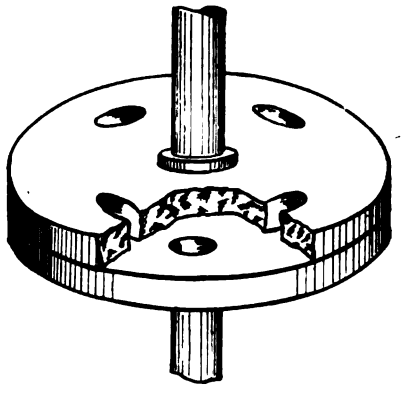


FIG. 248.—MANN'S DISCS.

of liquor rather than a continuous flow, and in such cases the tumbler may be conveniently employed. Another means of providing for intermittent flow is by introducing the principle of Mann's discs (Fig. 248). The upper disc revolves whilst the lower remains stationary, so that when the holes in the discs coincide a flush of water or liquor is given.

THE CAPACITY OF WASHERS AND SCRUBBERS

The necessary capacity of the washing and scrubbing plant depends very largely on the type of apparatus employed. Owing to the introduction of more efficient plant the size of the vessels has undergone some considerable reduction of late years. For washers of the Livesey and similar types the following rule is reliable :—

Allow $\frac{1}{7}$ to $\frac{1}{5}$ cubic foot of capacity per 1,000 cubic feet of gas passed per diem.

The standard sizes of Livesey washers for dealing with various quantities of gas may be taken as follows :—

Gas dealt with per 24 Hours.	Length and Width of Washer.	Depth of Washer.
	ft. in. ft. in.	ft. in.
3½–4 million cubic feet	20 0×7 6	3 6
2½–3 „ „ „	15 0×7 6	3 6
1½–2 „ „ „	10 0×7 6	3 6
¾–1 „ „ „	5 0×7 6	3 6
500–750,000 „ „	6 0×4 0	3 0
300–500,000 „ „	5 0×3 6	2 6
200–250,000 „ „	3 0×4 0	2 6
75–100,000 „ „	3 8×1 3	2 6

For mechanical washer-scrubbers an allowance of ½ to ¾ cubic foot per 1,000 cubic feet of gas passed per diem may be made.

Scrubbers

When there is *no other* wet purification plant, a generally recognized rule for the capacity of tower scrubbers states that 9 cubic feet of volume should be allowed for every 1,000 cubic feet of gas passed per diem. For modern requirements, however, so great an allowance will in most cases prove unnecessary; but much depends upon the washing apparatus prior to the scrubbing plant. In the scrubbers slow contact is desirable, so that the gas should be in contact with the wetted surfaces for a period of from ten to fifteen minutes, as against about twenty seconds in the modern form of washer-scrubber. When associated with any form of mechanical washing apparatus 5 or 6 cubic feet of scrubber capacity per 1,000 cubic feet of gas per diem should prove ample. In some cases the gas issuing from the power-driven vessel is practically devoid of ammonia, and is merely passed through a small tower scrubber operated with clean water and working as a catch vessel. Such a scheme, however, is not to be recommended, unless ample safeguards are provided against the breakdown of the mechanical machine. Where no washer-scrubbers are in use the capacity allowed should be as much as 10 cubic feet per 1,000 cubic feet of gas per diem. This includes both washer and scrubber capacity in such cases where only board-filled washers and coke or board scrubbers are employed, and may be apportioned half to the one type of vessel and half to the scrubbers. When washers on the Livesey and such principles are introduced the scrubber allowance need be no more than 6 cubic feet per 1,000 cubic feet of gas per diem. In very small works where one tower scrubber alone, and no washer, is in operation, the allowance may wisely be increased to 12 cubic feet.

The following are the sizes of scrubbers which may be effectively employed for the removal of ammonia *where no other plant* (*i.e.* washers) is in use for this purpose. In giving the actual size of scrubbers this is the only case which can be readily dealt with, when no details of the washing apparatus are known.

Single Scrubbers

Gas made per Day.	Scrubber.	
	Diameter.	Height.
	ft. in.	ft. in.
20,000 cubic feet	3 6	24 0
40,000 „ „	4 6	32 0
60,000 „ „	5 0	36 0
80,000 „ „	6 0	35 0
100,000 „ „	7 0	35 0
150,000 „ „	8 0	35 0
200,000 „ „	9 0	40 0
300,000 „ „	10 0	40 0

	Two Scrubbers in Series				
	ft.	in.	ft.	in.	
100,000 cubic feet	5	0	30	0	each
200,000 „ „	6	0	35	0	scrubber
300,000 „ „	7	0	40	0	of these
500,000 „ „	9	0	40	0	dimensions.
1,000,000 „ „	12	0	45	0	
1,500,000 „ „	14	0	50	0	

It will be noticed that for the smaller scrubbers the ratio of diameter to height is very much greater than is the case with the larger capacity vessels. In the case of single scrubbers it will be seen that works making up to 300,000 cubic feet per diem have only been considered, as it is inconceivable that larger concerns than this would be provided with one scrubber alone. The same remarks apply to the two scrubbers, where the limit has been placed at 1½ million cubic feet per day. It cannot be urged too strongly that the process of condensation should be carried out in an adequate and scientific manner. Effective condensation means an enormous reduction in the requisite scrubber capacity.

AMOUNT OF WATER REQUIRED

No hard and fast rule can be laid down in connexion with the amount of water necessary to remove completely the ammonia from the gas. Much must depend on the amount of this compound present, and on the proportion of it which is eliminated and thrown down in the virgin liquor of the condensers, etc. It has been stated that, theoretically, the whole of the ammonia may be removed by admitting 3 gallons of water per ton of coal carbonized, but in practice such a result is never attained. In the ordinary way, the whole of the water employed is admitted to the final or clear-water scrubber, and in normal cases this amounts to 10 to 13 gallons per ton of coal carbonized. Much, however, depends upon the type of scrubber in use, coke filling requiring a greater quantity of water than is the case with board filling. Much variation is shown in the direction of water consumption, and the author can point to cases where, with no other washing apparatus but scrubbers in use, the quantity admitted amounts to only 4 gallons per ton of coal. The horizontal washer-scrubber does not effect any marked economy in water, and in most cases requires an amount equal to about 10 gallons per ton of coal. Vertical washer-scrubbers of the centrifugal type are, however, very much more efficient in this respect, and a small quantity of water, admitted at the top, will, if desired, remove the whole of the ammonia. At Salisbury it was found that with clean water admitted to a vertical machine at the rate of 3¾ gallons per ton of coal carbonized 90 per cent. of the ammonia present in the gas at the inlet was retained, whilst the water passed off as a 16 oz. liquor. Thos. Glover has given figures for the quantity of liquor which should be distributed in scrubbers in order that these vessels may perform their work most efficiently. He states that the liquor distributed per square foot of cross-sectional area of the scrubber should be 0·145 gallons per minute. This is less the clean water added to the final scrubber.

AMMONIA LOST THROUGH SCRUBBERS

Many engineers, nowadays, make a practice of allowing a very small amount of ammonia to travel forward from the scrubbers to the purifiers. In this way the oxide of iron is maintained in an alkaline condition and fulfils its functions more satisfactorily. The amount of ammonia permitted to travel forward varies from 0·5 to 1 grain per 100 cubic feet.

In making tests for the quantity of ammonia passing through the scrubber it is preferable to calculate the total ammonia loss rather than to state the quantity in so many grains per 100 cubic feet of gas. Only by considering the total quantity of gas passed can the actual loss, which should be stated in the equivalent of so many gallons of 8 oz. or 10 oz. liquor, be gauged. The following is the method of making the calculation:—

Total grains of ammonia lost per week

$$= \frac{\text{Gas made for week}}{100} \times \text{No. of grains per 100 cubic feet at scrubber outlet.}$$

In 1 gallon of 10 oz. liquor there are 1,522 grains of ammonia.

∴ Quantity of 10 oz. liquor lost (in gallons)

$$= \frac{\text{Total grains of ammonia lost per week}}{1{,}522}$$

LIQUOR PURIFICATION

Attempts have been made to dispense with dry purification plant by making use of the alkaline impurity (ammonia) for removing the whole of the remaining acid substances. As previously pointed out, however, the available ammonia in coal gas (after the condensers have been passed), amounts, theoretically, to only half the quantity necessary for extracting the acid impurities. It has been proposed to overcome the difficulty of this deficiency by causing the ammonia to perform its duties twice; in other words, having absorbed the acid impurities the resultant salts are decomposed in special apparatus, when the acid gases are expelled and the ammonia rendered available for further use. Purification systems based on such principles were introduced by Claus, also Laming, Livesey, and Hills. Although theoretically ingenious, their complicated nature prevented any development on a practical scale.

The Claus Process

The Claus process is of particular interest, in that it was tried on a fairly large practical scale at the Belfast gasworks, but was ultimately abandoned as unsuitable. Simply explained, the process consists of the following:—

1. The crude liquor (*i.e.* saturated with sulphuretted hydrogen and carbon dioxide) from the washers is passed through a series of towers, where it is submitted

to the action of carbon dioxide gas. Sulphide of ammonia is, therefore, converted into the carbonate whilst sulphuretted hydrogen is liberated.

2. The sulphuretted hydrogen gas is then burned in a Claus kiln and yields solid sulphur.

3. The crude liquor, now consisting chiefly of ammonium carbonate, is passed into heating towers, in which its temperature is raised to from 180° to 200° Fahr. In this way the CO_2 is expelled from the liquor to the extent of from 60 to 75 per cent. of the quantity in which it is present. This CO_2, or rather a portion of it, provides the CO_2 gas current mentioned under (1).

4. The partly purified liquor from which the CO_2 has been liberated is then distilled so that ammonia gas and the remaining ammonium carbonate are evolved.

5. The ammonia gas and ammonium carbonate vapour are then passed through cooling towers, when the carbonate sublimes to the solid state, leaving a comparatively pure ammonia gas.

6. Lastly the ammonia is admitted to the stream of crude coal gas before the latter enters the washers.

In this way the original ammonia which has combined with CO_2 and SH_2 in the crude gas is recovered in the gaseous form and caused to react once more with the acids. A surplus of ammonia is, of course, obtained, and may be converted into sulphate of ammonia in the ordinary way.

Davidson's Process

The most recent process for the self-purification of crude gas is that introduced by Dr. W. B. Davidson. The principle of the process is on the same lines as those attempted by previous experimenters, but it is operated in a more scientific manner. The process of separating the acid gases from the ammonia is carried on in a vertical still of the usual pattern, to the top of which the liquor is fed. The still is heated by steam introduced at the base, and whilst the ammonia is taken off at a point half-way up the column, the CO_2 and SH_2 are expelled at the top. This separation of the ammonia and acid gases is made possible by graduating the temperature and pressure within the still—the pressure being so regulated that a comparatively high pressure is obtained in the portion of the still from which the ammonia is collected. After leaving the still, the gaseous ammonia is passed through absorbers to remove any traces of the acid gases, and is then re-mixed with the crude coal gas at any convenient point, such as the condensers or washers. From the washers, scrubbers, and condensers, the ammoniacal liquor is collected and returned to the still, whilst the surplus ammonia, being recovered in an extremely pure form, provides a valuable by-product. The working pressures in the still amount, as a minimum, to approximately 5 lbs. per square inch at the point where the steam is applied; 4 lbs. per square inch where the ammonia is withdrawn; and 3 lbs. per square inch at the zone where the acid gases are removed. Higher pressures than these (worked in the same ratio) will, however, give more satisfactory results. Though not essential to the process, Dr. Davidson prefers to treat

the gas which has passed the ordinary washers and scrubbers with a sludge of ferrous hydrate, prepared from iron chloride or sulphate and ammoniacal liquor. In this way the whole of the sulphuretted hydrogen may be removed. The process then resolves itself into the following:—

1. *Tar extractor.*—Tar in crude gas reduced to less than 2 grains per 100 cubic feet.

2. *Cyanogen washer.*—Iron sulphide sludge employed for removing cyanogen:—$FeS + 6HCN + 4NH_3 = (NH_4)_4FeC_6N_6 + SH_2$. Ammonium ferrocyanide is thereby formed, with the liberation of sulphuretted hydrogen.

3. *First ammonia washer.*—To which the ammonia gas liberated from the liquor is admitted, thus extracting the bulk of the sulphuretted hydrogen and carbon dioxide.

4. *Second ammonia washer.*—In which water is used for removing any remaining ammonia, SH_2 and CO_2. The SH_2 is reduced to less than 0·02 per cent. by volume.

5. *Final washer.*—In the lower portion of this washer, a ferrous hydrate sludge is used to extract the last traces of SH_2 and a further quantity of ammonia, as follows:—

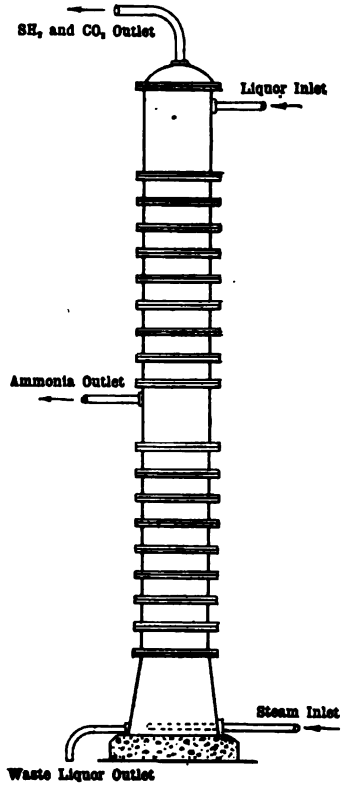


FIG. 249.—DAVIDSON'S AMMONIA STILL.

Iron sulphate is treated with ammoniacal liquor to give ammonium sulphate. $FeSO_4 + 2NH_4OH = (NH_4)_2SO_4 + Fe(OH)_2$. The SH_2 then combines with the iron hydrate formed:—$Fe(OH)_2 + SH_2 = FeS + 2H_2O$. The iron sulphide resulting from this reaction is afterwards made use of for absorbing cyanogen, as explained under heading (2). In the upper portion of the final washer, water or sulphuric acid is used for extracting the last traces of ammonia.

DIRECT METHODS OF RECOVERY

During recent years, some considerable attention has been given to the problem of recovering the ammonia resulting from the distillation of coal by direct means. In the ordinary way, this ammonia is wholly recovered in the form of an ammoniacal liquor, the liquor being subsequently worked up into sulphate of ammonia in a distinct plant. Chemists, particularly on the Continent, have endeavoured to obviate the necessity for providing a separate unit for working up the ammonia into commercial form, and have introduced processes for the "direct" recovery of the by-product in the ordinary course of gas-making. The "direct"

methods now employed for the recovery of ammonia may be classified under two headings, namely:—

(*a*) Those in which the acid impurity, sulphuretted hydrogen, is utilized to form sulphate of ammonia.

(*b*) Those in which the crude gas is passed through a seal of sulphuric acid, thereby causing sulphate of ammonia to be deposited. These processes are sometimes referred to as "semi-direct" methods.

The ideal process is undoubtedly that in which the use of sulphuric acid is unnecessary. Although the practical difficulties attending such methods are many, Burkheiser and Feld have already met with some considerable success in this direction, and their schemes may now be said to be beyond the experimental stage. They cannot, however, lay claim to having reached, as yet, a stage of perfection.

The Burkheiser Process

In Burkheiser's process, the usual practice of extracting ammonia prior to sulphuretted hydrogen is reversed—the sulphur impurities being removed first. The *modus operandi* of the plant can be followed best by referring to the diagram, Fig. 250. The crude gas coming away from the tar extractor is first pre-heated by means of a steam coil. It then travels through a form of still, where the ammonia is expelled from any virgin liquor thrown down in the condensers, etc., and is carried forward by the crude gas. The sulphuretted hydrogen is then extracted by passing the gas through purifiers containing Burkheiser's patent oxide. This oxide has been subjected to a special process of roasting, by means of which the organic matter and moisture are removed, leaving the material in the form of small nodules. The activity of the oxide is so increased by this means that it is capable of removing sulphuretted hydrogen at a speed thirty times greater than is the case with ordinary oxide. The apparatus is in two similar sections, one portion being used for purifying the gas whilst the other is given up to revivification of the oxide. The two sections change places at intervals—the one which was revivifying doing the purification, and *vice versa*. After leaving the ammonia still, the gas passes through special oxide of iron in the purifier and thence into the base of the ammonia washer. An acid solution is admitted to the top of the washer, and in this way the ammonia is neutralized and washed out from the gas. The neutral liquor, or lye, flowing from the washer is collected and used in the other side of the plant. The gas, free from all impurities, passes out at the top of the ammonia washer as shown.

When the oxide has absorbed its maximum quantity of SH_2, the gas is deflected from the right-hand side, and is passed through the left-hand side of the plant, where the oxide (previously fouled) has been undergoing revivification; whilst the former purifying side is now submitted to an air-blast, so that this oxide may be revivified. Revivification is carried out by passing a powerful air-blast through the spent oxide, and the compounds of sulphur and iron are violently oxidized so that sulphurous acid is produced. The air-blast (laden with the acid) then passes

to the washer, where it meets with a stream of neutral liquor produced in the other side of the plant—this absorbing the acid gases and running out as an acid lye from the bottom of the washer. This acid liquor is then pumped over to the opposite side of the plant, and is utilized for absorbing ammonia as before explained. A

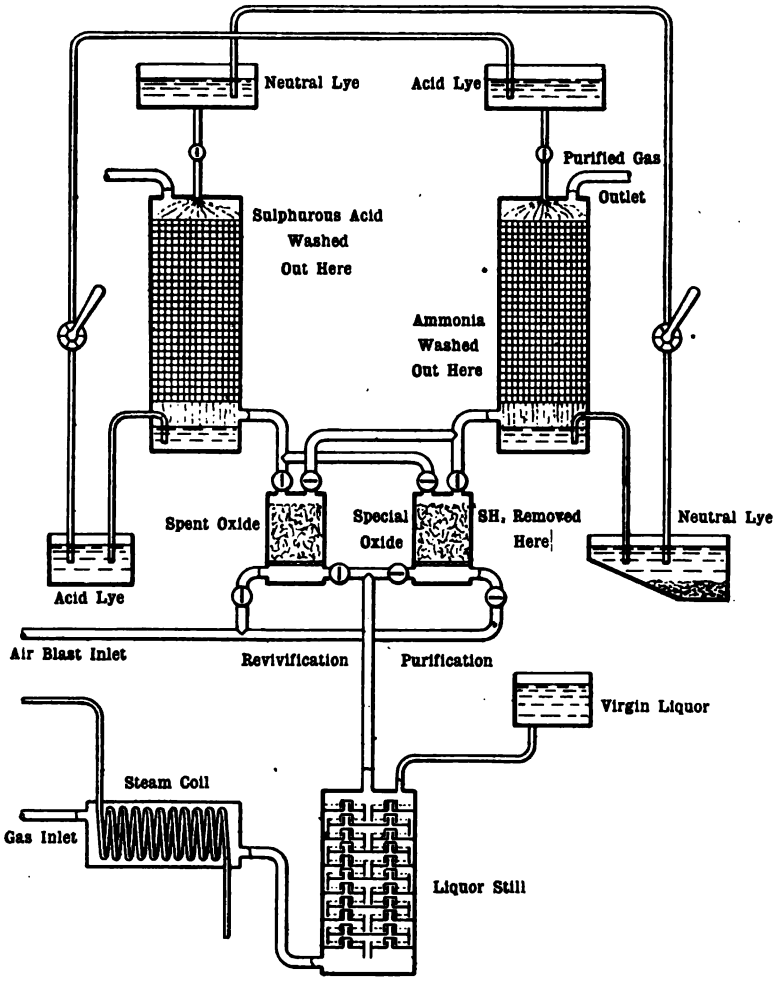


FIG. 250.—LINE DIAGRAM SHOWING BURKHEISER'S PROCESS.

definite volume of liquor is thus kept in circulation, and becomes gradually charged with salt until the saturation point is reached, when the salt is deposited at the bottom of the neutral lye tank as ammonium sulphite and sulphate, the reaction being :—$H_2O + SO_2 + 2NH_3 = (NH_4)_2SO_3$ (sulphite). The sulphite is then oxidized into sulphate, taking up another atom of oxygen from an air-blast. For this pur-

pose the apparatus shown in Fig. 251 is used, the sulphite being first heated by a steam jacket and sublimed thereby.

The cylinder in which the worm conveyor works is jacketed for the first half of its length with cold water, and for the second half with steam. The sulphite, on reaching the heated portion, is volatilized and driven back again by a blast of air entering at the outlet end, this air converting the sulphite into sulphate, which is then deposited. The principle of the apparatus is dependent upon the fact that ammonium sulphite is sublimed at temperatures below 100° C., whereas the sulphate is not. The salt thrown down in the liquor tank consists of about 67 per cent. sulphite, and the remainder sulphate.

In a process of this kind there is some liability to accident owing to over-heating during the revivification of the oxide. This, however, is guarded against by arranging a system of water-cooling for the oxide, also by ensuring the presence of water vapour in the blast. In practice, there is little fear of danger unless a temperature of 570° Fahr. is exceeded; and in the Burkheiser plant the temperature rarely rises above 285° Fahr. Moreover, as a safeguard, an electric alarm thermometer is fitted to the purifier undergoing regeneration.

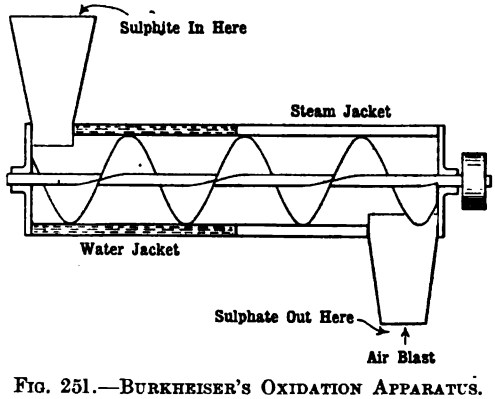


FIG. 251.—BURKHEISER'S OXIDATION APPARATUS.

In a process of this kind there is, of course, an excess of sulphur over that necessary to neutralize the whole of the ammonia. This surplus may be recovered for sale in various ways. The salt obtained by the process is of a somewhat inferior quality, owing to the incomplete nature of the oxidizing process, and, consequently, the presence of ammonium sulphite.

THE FELD PROCESS

The Feld plant affords another means of arriving at the same result as is obtained in the Burkheiser system, *i.e.* the recovery of ammonia as sulphate of ammonia by causing it to combine with the sulphur impurities. The Feld plant extracts ammonia and sulphuretted hydrogen simultaneously, at the same time oxidizing an amount of sulphuretted hydrogen equivalent to the ammonia in the gas. Sulphate of ammonia is yielded, whilst the surplus sulphur is obtained in the solid form. Within the last year or so, the plant has undergone some modification; the original process is, however, of considerable interest, and is described in outline below. For the sake of simplicity, the various stages in the working are sub-divided under different headings, so that there should be no difficulty in following out the scheme with the aid of the accompanying diagram (Fig. 252).

Process 1.—Gas containing NH_3 and SH_2 is washed with a weak solution of

ferrous sulphate. Sulphate of ammonia is formed, and sulphide of iron precipitated—

(*a*) $FeSO_4 + 2NH_4OH = (NH_4)_2SO_4 + Fe(OH)_2$

(*b*) $Fe(OH_2) + SH_2 = FeS + 2H_2O$

Process 2.—The iron sulphide liquor is treated with SO_2, which is obtained by the burning of sulphur. Free sulphur is precipitated, and soluble ferrous thiosulphate, thionate, and sulphate are formed—$2FeS + 3SO_2 = 2FeS_2O_3 + S$.

Process 3.—This liquor (FeS_2O_3) is again used for treating the gas—$2FeS_2O_3 + 4NH_3 + 2H_2S = 2FeS + 2(NH_4)_2S_2O_3$. The reaction this time is somewhat different. The ammonia and SH_2 in the gas are again absorbed, whilst iron sulphide, together with some free sulphur, is precipitated—sulphate, thiosulphate, and thionate of ammonia being formed. The liquor is alternately treated with crude gas and SO_2 until it contains from 30 to 45 per cent. of ammonia salts.

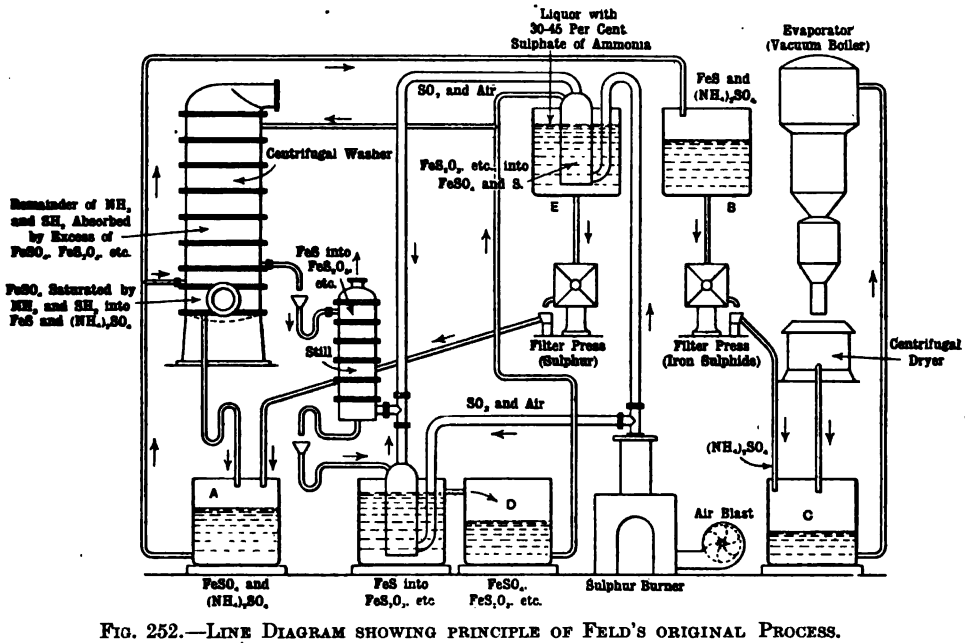


FIG. 252.—LINE DIAGRAM SHOWING PRINCIPLE OF FELD'S ORIGINAL PROCESS.

Process 4.—The liquor undergoes oxidation, by which process the thiosulphate and thionates are transformed into sulphate. To do this the hot liquor is treated with SO_2, and an excess of air. The ferrous sulphide is dissolved, and the ammonia all converted into sulphate, whilst free sulphur is precipitated—$2FeS + 2(NH_4)_2S_2O_3 + 3SO_2 + 2O_2 = 2(NH_4)_2SO_4 + 2FeSO_4 + 5S$.

Process 5.—The free sulphur is separated from the liquor by filtration.

Process 6.—The liquor coming from the filter-press, and containing the sulphate of ammonia, also sulphate of iron, is treated with the crude gas (containing SH_2 and NH_3), by the action of which the ferrous sulphate is decomposed, forming again sulphate of ammonia and iron sulphide (see under Process 1). The iron is separ-

ated by filtration, and the liquor containing the sulphate is evaporated, leaving the salt behind—this being dried in a centrifugal machine.

The diagram shows the plant complete. The washing liquor is pumped to the Feld centrifugal washer, and, on leaving, passes through the "still," being collected in the lower tank. Here (also in the still) the liquor meets with SO_2, which brings about the regeneration of the FeS into sulphates. As soon as the liquor contains 30 to 45 per cent. of ammonia sulphate, it is pumped to the upper tank, while the lower one is filled with fresh liquor. The salts are converted wholly into sulphates in this upper tank. The sulphur is then separated out in the filter press, and the liquor coming away from this is continuously pumped round and round into the lowest bay of the washer. The object of this is to completely precipitate the iron from the sulphate solution. The iron sulphide mud is then filtered out in the second press, and the liquor evaporated and dried.[1]

In the Feld process, as recently modified, the use of the iron or zinc salt is discontinued. As a washing medium, a solution is used containing ammonia, sulphur, and sulphurous acid, also ammonium thiosulphate and polythionates. In the washer the ammonia and sulphuretted hydrogen are absorbed, with the conversion of the ammonium polythionate into thiosulphate.

$$(NH_4)_2S_4O_6 + 2NH_3 + H_2S = 2(NH_4)_2S_2O_3 + S.$$

(Ammonium Tetrathionate) (Ammonium thiosulphate).

After a time, the spent liquor running from the washer is treated with SO_2 from the kiln and regenerated at about 100° Fahr—$2(NH_4)_2S_2O_3 + 3SO_2 + S = 2(NH_4)_2S_4O_6$. This regenerated liquor is again used in the washer, and by its continuous circulation the ammonium salts increase in quantity until eventually crystals are deposited. The liquor is then boiled, the sulphur is precipitated and filtered out, and the remaining liquor is evaporated in a vacuum boiler, producing crystals of sulphate of ammonia—$(NH_4)_2S_4O_6 = (NH_4)_2SO_4 + SO_2 + 2S$. The sulphur dioxide evolved is used for regeneration purposes. In addition to the equation given above for the reaction of the polythionate in the ammonia washer, the following reaction also occurs—

$$(NH_4)_2S_4O_6 + 3H_2S = (NH_4)_2S_2O_3 + 5S + 3H_2O$$

Semi-Direct Processes

These processes, although, scientifically, not so perfect as those discussed above, in view of the necessity for introducing sulphuric acid, are undoubtedly more desirable, owing to the ease with which they may be operated in practice. When plants of this description are employed, the ordinary washing and scrubbing apparatus is dispensed with—the ammonia being removed by bubbling the gas through a seal of sulphuric acid. The chief points requiring attention in order to make the

[1] See *Journal of Gas Lighting*, vol. cvii. p. 816; also *Gas World*, vol. lvii. p. 250.

process a success are the entire elimination of all tarry matter from the gas and the maintenance of the acid bath at such a temperature as to allow of the formation of the salt.

The Koppers system of semi-direct recovery is shown diagrammatically in Fig. 253. The hot gas coming direct from the ovens enters the coolers or condensers, where it is reduced in temperature to about 75° Fahr. The gas then passes to the exhauster and is taken through a tar extractor of some efficient type. After the tar has been removed, the gas is led through the re-heater, where, by means of exhaust steam, its temperature is raised to about 130° Fahr. The heated gas then passes to the saturator, where the ammonia is recovered from it by absorption in sulphuric acid. The sulphate as it is formed falls to the bottom of the vessel and is continuously removed by means of a steam or compressed air ejector. Finally, the sulphate is

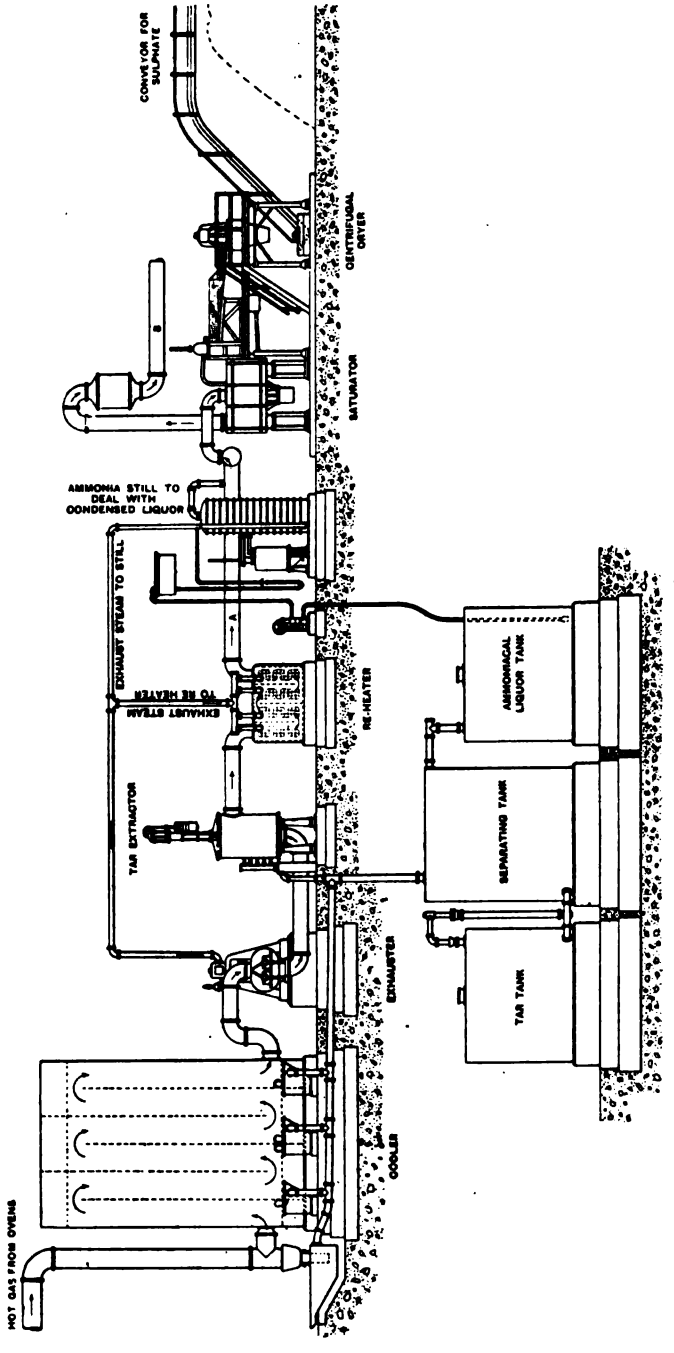


FIG. 253.—KOPPERS DIRECT PROCESS.

delivered to a centrifugal drying machine, in which the mother liquor is removed from it. The condensate thrown down in the coolers, also the overflow products from the tar extractor, are run to the separating tank, which is so arranged that tar and liquor can separate, owing to the difference in their specific gravities. The two products then flow into their respective storage tanks. The virgin liquor is finally pumped up into the ammonia still, where it is heated with steam and lime in the usual way. The ammonia, sulphuretted hydrogen, and carbon dioxide, resulting from the distillation of the liquor, are then admitted to the crude gas main at a point just preceding the saturator.

CHAPTER XV

THE RECOVERY OF CYANOGEN

THE presence of hydrocyanic acid amongst the products of the distillation of coal has been recognized for a number of years, and many and varied attempts have been made to effect its recovery on profitable lines. The amount of hydrocyanic acid occurring under normal conditions is, however, comparatively small, so that in many cases the working expenses of the process adopted have rendered recovery unprofitable, except in the case of the largest concerns. From a commercial point of view, cyanogen derives its value from the fact that the principal method of treating rocks and quartz for the recovery of gold is by the cyanide process, with or without amalgamation on copper plates. The *rationale* of the process is the crushing of the gold-bearing rock in a suitable machine, the admixture of the fines with water, so as to form a sludge, and, finally, the passing of this sludge over copper plates amalgamated with mercury. The fine gold then commixes with the mercury, whilst the residue of crushed ore flows away. The waste is known as " tailings." Periodically, that is after every three or four weeks, the copper plates are scraped, and the amalgam obtained is distilled in a retort, whence the mercury is evolved and the gold left behind. The mercury treatment is still employed in conjunction with cyanide, although in many cases the ore is treated direct and the amalgamation process is dispensed with. To-day, the greater portion of the gold output of the world is obtained by means of the cyanide method. Briefly, the process consists of two essential parts :—

(*a*) Dissolving the gold from the ore in a cyanide solution.
(*b*) Precipitation of the gold from the solution.

The mineral as won from the mines is primarily subjected to several sortings, and is then treated in large vats with a solution of sodium, or occasionally potassium, cyanide. An extremely weak solution is usually employed, owing to the fact that the greater the percentage strength of the cyanide the more easily are metals other than gold dissolved. The period of treatment generally varies from twelve to twenty-four hours, and in cases where the mineral may require extended contact the cyanide solution should be renewed every three or four days. Precipitation of the gold from the cyanide solution is usually carried out by means of zinc, the latter displacing the gold from the cyanide as follows :—

$$2NaAu(CN)_2+Zn=Na_2Zn(CN)_4+2Au.$$

The process, however, is not so simple as might be supposed from the above brief outline, and many modifications have been introduced from time to time with the object of rendering the work more economical and of increasing the efficiency of recovery. In addition to being employed for the treatment of gold-bearing ores, cyanides find a limited use in the manufacture of dyes and paints, and in electro-plating.

CYANOGEN IN COAL GAS

The cyanogen in coal gas is almost wholly in the form of hydrocyanic acid, although some authorities say that it is also present as free cyanogen and ammonium cyanide. Hydrocyanic acid is produced by the combination of hydrogen, carbon, and nitrogen at high temperatures in the retort, and makes its appearance among the products at temperatures considerably higher than those at which ammonia is at a maximum (1,000° Fahr.). It is probable that a portion of the ammonia itself is split up into its elements, hydrogen and nitrogen, these re-combining, with the addition of the carbon atom, to form hydrocyanic acid (HCN). As regards the original nitrogen in coal, it has been shown that less than 2 per cent. of this goes to form cyanogen, the quantity of the latter considerably increasing when high and extreme temperatures of distillation are employed (*see* page 257). The most favourable temperature in the retorts for the formation of cyanogen is said to be 2,200° Fahr., and the maximum amount recoverable from a ton of English coal is about 1½ lb. of hydrocyanic acid, or about 10,000 grains.

Cyanogen compounds may be found :—

(*a*) In the gas, chiefly as hydrocyanic acid.

(*b*) In the ammoniacal liquor, mainly as ammonium cyanide, ferrocyanides, and sulphocyanide.

(*c*) In spent oxide, chiefly as " Prussian blue " (ferric-ferrocyanide).

(*d*) In spent lime, as calcium sulphocyanide, and to some extent as calcium ferrocyanide.

(*e*) In spent liquor from the sulphate plant, as ferrocyanide compounds.

The chief processes nowadays, in this country at any rate, are those by means of which the cyanogen is extracted from the gas and recovered as either (*a*) ammonium sulphocyanide (NH_4SCN) or sodium ferrocyanide (prussiate of soda, $Na_4FeC_6N_6$). Ultimately the sulphocyanide or prussiate is converted into sodium cyanide for gold working processes; and, so far as this operation is concerned, recovery as prussiate is to be preferred.

Per se, the extraction of cyanogen as a distinct by-product will, in normal times, only prove profitable in the case of the larger gasworks. Indirectly, however, the removal of the compound from the gas presents many advantages, and if it could be generally extracted and turned to profitable account the task of the gas engineer would certainly be made easier. Apart from the fouling of gasholder water, and the possible corrosion of gasholder plates and other apparatus, the removal of the cyanogen is strongly to be urged, owing to its effect on the effici-

ency of the present-day purifying material. It is beyond all question that oxide of iron, whether natural or artificial, will remain in an active condition for a much greater length of time when the cyanogen is absent. Both Bueb and Guillet have shown that in some cases the efficiency of the " dry " purifiers may be increased by so much as 50 per cent. if the compound is extracted. Perthuis has pointed out that in certain circumstances cyanogen is responsible for a reaction—not wholly understood—in the purifiers which may cause the material in them actually to increase the sulphur impurities in the gas.

On works where no recovery plant for cyanogen is in use the bulk of the substance will be removed by the oxide or lime purifiers, although some slight reduction will take place during the passage of the gas through the wet purification plant. No definite statement can be made as to the amount of cyanogen which will pass through the oxide boxes. In many works the gas at the outlet of the purifiers shows only a trace, while in other cases as much as 8 to 10 grains of hydrocyanic acid per 100 cubic feet of gas will be found. The cyanogen, by combining with the iron salts, is absorbed in the purifiers as ferrocyanides. In this way a portion of the active material is rendered inert so far as the absorption of sulphuretted hydrogen is concerned. The Prussian blue, moreover, by coating the granules of the oxide, exerts an effect far greater in proportion than the actual extent in which it is present. Spent oxide with a content of 25 per cent. of sulphur has been found to contain as much as 12½ per cent. of Prussian blue, although in normal cases the amount of the latter present will not exceed 4½ per cent. As regards the formation of Prussian blue in the purifying boxes the reactions taking place are by no means simple, and there seems little doubt that the ferric-ferrocyanide is the result of oxidation of a ferrous cyanide which is formed in the first instance. Thus the hydrocyanic acid reacts with the oxide of iron :—

$Fe_2O_3+4HCN=2Fe(CN)_2$ (ferrous cyanide)$+2H_2O+O$, and by oxidation gives :—

$18Fe(CN)_2+3O_2=2Fe_2O_3+2Fe_4,3Fe(CN)_6$ (Prussian blue).

Many different opinions have been expressed as to the probable reactions accounting for the Prussian blue, and although the above seems reliable, it is open to some questioning. Again, there is a likelihood that the hydrocyanic acid does not react with the active material (Fe_2O_3), but with the iron sulphide, and the experiments of Leybold would appear to corroborate this. The mode of reaction in this case would then be :—

$$FeS+2HCN=SH_2+Fe(CN)_2$$

The ferrous cyanide is finally oxidized to ferric-ferrocyanide as shown above. The chief point to notice is that moisture or the admission of steam to the boxes will aid the formation of Prussian blue whilst ammonia will prevent it. The presence of ammonia in the crude gas, therefore, greatly facilitates the formation of sulphocyanides and on this account is desirable. The sulphocyanides formed, being of a soluble nature, are, accordingly, run off from the material through the drain-pipes of the purifier and do not form a film on the granules of oxide as is the case with the ferrocyanide. The action of the ammonia is not perfectly clear, and it

cannot be (as so often stated) that it combines direct with the hydrocyanic acid and sulphur to form ammonium sulphocyanide as in the polysulphide process (*see* page 372), for the amount of ammonia required would be greatly in excess of that actually present in the gas at this point. It is well known, however, that the formation of Prussian blue cannot take place when alkaline conditions prevail, so that if a small quantity of ammonia (about 1 grain per 100 cubic feet) is allowed to travel forward in the gas from the scrubber the formation of Prussian blue in any quantity will very seldom follow. The same effect, however, is not seen when an alkali such as lime is mixed in small proportion with the oxide in the purifiers, owing to the lime being quickly carbonated by the CO_2 coming forward with the gas.

THE RECOVERY OF CYANOGEN FROM THE GAS

As already stated, the cyanogen recovered as a by-product in the gasworks of this country is, without exception, removed from the gas alone. On the Continent the spent oxide is more frequently treated for the purpose; but, in general, the class of coal employed gives higher yields of cyanogen than do English coals. Of the more important processes which have been adopted in this country the following may be mentioned, although some have been discarded in favour of more modern methods:—

(*a*) The Foulis process (prussiate of soda).
(*b*) Wilton's process (prussiate of soda).
(*c*) The British Cyanides Company's process (sulphocyanide).
(*d*) The Davis-Neill process (prussiate of soda).
(*e*) The polysulphide process (sulphocyanide).

Other processes of interest are those of Ciselet and Deguide, and of the South Metropolitan Gas Company in collaboration with the Thann Chemical Manufacturing Company, of Alsace.

The Foulis Process

The Foulis process was patented in 1892 and first put into operation at the Glasgow gasworks. Chloride of iron is made by dissolving scrap iron in hydrochloric acid in large vats, preferably made of slate. The iron chloride is then mixed with the requisite quantity of sodium carbonate so that iron carbonate results—

$$FeCl_2+Na_2CO_3=FeCO_3+2NaCl.$$

The iron carbonate is precipitated and the sodium chloride is run to waste. The iron carbonate is then removed to a further tank, where it is mixed with more sodium carbonate in the necessary theoretical quantities. The tank is provided with a stirrer and has an outlet leading into the first bay of a suitable washer-scrubber. The mixture is run direct into the washer and, combining with the hydrocyanic acid in the gas, is converted into sodium ferrocyanide, which is run away from the final bay as quickly as it is produced—

$$FeCO_3+2Na_2CO_3+6HCN.$$
$$=Na_4Fe(CN)_6 \text{ (sodium ferrocyanide)}+3CO_2+3H_2O$$

The crude ferrocyanide is evaporated nearly to dryness in pans, and when cool—and, consequently, solid—it is wheeled to the stores. In this condition it contains about 75 per cent. of sodium ferrocyanide. Oxidation of the $FeCO_3$ can be prevented by mixing in one bay of the washer-scrubber and by adding the whole of the sodium carbonate at one time.

Wilton's Process

In Wilton's process cyanogen is arrested in the process of scrubbing by adding to the rotary washer-scrubber an iron salt. It is more or less essential that the liquor in the washer-scrubber should be strong, *i.e.* about 16 oz., otherwise the whole of the hydrocyanic acid will not be arrested. Ammonium ferrocyanide is formed as follows:—

$$FeSO_4+6HCN+6NH_4OH=(NH_4)_4Fe(CN)_6+(NH_4)_2SO_4+6H_2O$$

and is afterwards converted into Prussian blue by the addition of a further quantity of iron—

$$3(NH_4)_4Fe(CN)_6+2Fe_2(SO_4)_3=Fe_4,3Fe(CN)_6+6(NH_4)_2SO_4.$$

British Cyanides Company's Process

The process of the British Cyanides Company, of Oldbury, recovers the hydrocyanic acid in the form of a sulphocyanide. The method consists essentially of the preparation of a solution containing ammonium polysulphide by the addition of coarsely powdered sulphur to ordinary ammoniacal liquor. A rotary washer-scrubber, usually of the Holmes type (*see* page 343) is employed for bringing gas and liquor in through contact, and the top of each bay is provided with a cup-shaped receiver having a closely fitting lid. These cups are periodically filled with the powdered sulphur, and the ammonium sulphide in the liquor combines with the free sulphur added to give ammonium polysulphides, $(NH_4)_2S_2$ to $(NH_4)_2S_5$. The process is dependent upon the fact that whereas hydrocyanic acid will combine with ammonium polysulphide, it will not enter into action with ammonium sulphide. Ammonium sulphocyanide is formed in the washer, the liquor flowing out with a strength varying from 15° to 20° Twaddel. With the disulphide the equation of the reaction occurring is as follows—

$$(NH_4)_2S_2+HCN=NH_4SCN+NH_4HS.$$

Whilst the plant is in operation it is usual to test the liquor in the various bays of the washer-scrubber from time to time in order to ensure that it consists of ammonium polysulphide and not the sulphide. This may be done by adding a small quantity of acid to the liquor, when a decided precipitate of sulphur will be given if the polysulphide is present, whilst the sulphide will give practically no precipitate at all. In this system the hydrocyanic acid is extracted before the ammonia has been removed from the gas, as in this way the proportion of ammonium sulphide is increased and the efficiency of extraction rendered higher. To this end the plant is usually placed immediately after the exhausters, with some efficient form of tar extractor coupled up to its inlet.

It is found that by the British Cyanides process practically the whole of the hydrocyanic acid is removed from the gas, and the liquor may be readily worked up to a strength of from 3 to 4 lb. of ammonium sulphocyanide per gallon. As regards ammonia, the strength of the liquor may be as high as 40 oz., but 90 per cent. of the ammonia is present in the "fixed" state. In the case of some works the liquor is passed on to the sulphate plant and treated for the recovery of ammonia in the ordinary way, by the addition of lime. The lime then takes the place of the ammonia and gives rise to calcium sulphocyanide, which may be sold direct to the cyanide agents, by whom it is converted into sodium cyanide. The conversion of ammonia into calcium sulphocyanide takes place as follows:—

$$2(NH_4SCN)+Ca(OH)_2=Ca(SCN)_2+2NH_4OH.$$

It has been found that in addition to absorbing hydrocyanic acid some reduction of the carbon disulphide in the gas may take place as the gas travels through the plant. But whilst in some cases so much as 20 to 25 grains of CS_2 per 100 cubic feet was absorbed, at other times a reduction of only 1 to 2 grains was shown. No reliance can be placed upon the apparatus for this purpose. Colman, however, in a series of experiments, found that in no case was the CS_2 increased during the passage of the gas through the washer, and an average reduction of 10 grains resulted from tests extending over some period. The exact manner in which the CS_2 is absorbed is not perfectly clear, but it may unite with the ammonium sulphide to give ammonium thiocarbonate (*see* page 331) as follows—

$$(NH_4)_2S+CS_2=(NH_4)_2CS_3.$$

The carbonic acid in the gas is prejudicial to the absorption of CS_2, for it reacts with thiocarbonate and drives the CS_2 out of its combination. When the CO_2 content in the gas is low the efficiency of CS_2 absorption should, therefore, be increased. The ammonium thiocarbonate gradually becomes converted into ammonium sulphocyanide in the washer—

$$(NH_4)_2CS_3=NH_4CNS+2H_2S,$$

so that in this way the carbon disulphide removed is turned to useful account.

The Polysulphide Process

The British Cyanides Company are now giving up this process and substituting a more efficient and economical method, known as the polysulphide process. In the newer process the hydrocyanic acid is recovered in the form of ammonium sulphocyanide, but the necessity of introducing a special supply of free sulphur is obviated by making use of the sulphur in spent oxide for the production of the polysulphides. A diagrammatic sketch of the apparatus is shown in Fig. 254. From this it will be seen that the vessel employed resembles an ordinary dry purifier, access to which is obtained through portions of the top which are made removable on the lines of a Green's purifier. The inlet gas entering at the base of the vessel passes in the first instance through a tar extractor operated on the bubbling principle, the gas passing

through the cyanide liquor which forms the seal. Above the tar extractor is arranged, on suitable brackets, a tier of ordinary wooden purifier grids which support a layer of spent oxide, evenly spread over the whole cross-section of the vessel, and about

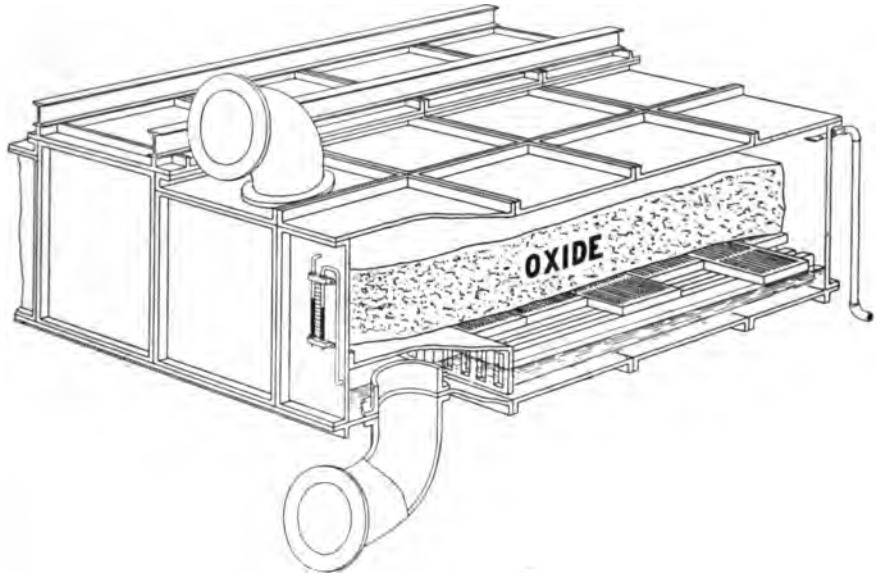


FIG. 254.—THE POLYSULPHIDE PLANT.

24 inches in depth. The spent oxide used should preferably be of good quality, containing not less than 50 per cent. of sulphur. It is kept in a moist condition by a simple arrangement of sprays fitted around the four sides of the vessel at a point well above the oxide level. These sprays may be seen in Fig. 255, which shows a complete section of the box with the two inlets and outlets for the gas. A short period of spraying every day with water or a weak cyanide liquor is all that is necessary. In this way the polysulphide solution is formed within the interstices of the oxide bed, and is immediately converted into ammonium sulphocyanide by the incoming gas. The cyanide liquor, after trickling through the oxide mass, drops to the base of the vessel, from which it overflows to the storage tank by way

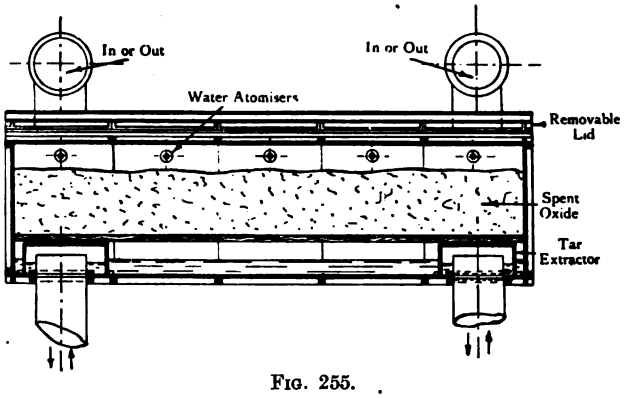


FIG. 255.

of a seal. With regard to the actual formation of the sulphocyanide it would seem that a straightforward reaction on the following lines takes place—

$(NH_4)_2S_2$ (ammonium polysulphide)$+HCN=NH_4SCN+NH_4.SH$.

There is, however, some probability that a portion of the sulphocyanide is formed in two stages, with the intermediate production of thiocyanic acid. Thus ammonium polysulphide gives ammonium sulphide and thiocyanic acid as follows—

(1) $(NH_4)_2S_2+HCN=(NH_4)_2S+HSCN$ (thiocyanic acid).

The last-named then combines with more ammonia, in the form of the hydrate, to give the sulphocyanide—

(2) $HSCN+NH_4OH=NH_4SCN+H_2O$.

Probably the most surprising feature of the polysulphide process lies in the fact that although sulphur is inevitably required for the completion of the reaction, the spent oxide, after working for some period, shows no loss in sulphur content, and occasionally some increase is found. It would seem, then, that there is a simultaneous absorption of ammonia, sulphuretted hydrogen, and oxygen, and that—as the oxide takes up SH_2, which is eventually oxidized to sulphur—a continuous supply of free sulphur is automatically provided. The process would, in fact, be continuous but that the physical condition of the spent oxide necessitates periodical removal from the vessel and the substitution of a fresh layer. The period for which the material will remain in action varies under normal conditions between three and six months. Six vessels now in operation at one gasworks have shown themselves capable of extracting practically the whole of the hydrocyanic acid over a period of six months without requiring remaking. The cyanide boxes are usually made either 20 or 25 feet square by 6 feet deep. The former size is capable of dealing effectively with 1½ million cubic feet of gas per diem, whilst the latter will take up to 2 million cubic feet. For larger volumes of gas the boxes are operated in parallel, although, when possible, it is preferable to arrange for two purifiers to be worked in series, so that the gas travels upwards through one and downwards through the second.

Figures obtained in actual practice show that one ton of spent oxide is capable of removing the whole of the cyanide from 350 tons of coal. One of the chief recommendations of the method is the manner in which the duties of washers, scrubbers, and dry purifiers are lightened. Of the ammonia contained in the crude gas entering the plant an average of from 30 to 35 per cent. is absorbed, the sulphuretted hydrogen shows a reduction of 35 per cent., whilst carbon dioxide falls off by from 5 to 12 per cent. No claim can be made for the absorption of carbon disulphide. It is essential to remember that there must be a small proportion of oxygen in the inlet gas. In general, this proportion varies between 0·2 to 0·6 per cent.; and—by oxidizing the iron sulphides in the purifier—gives rise to the free sulphur which is vital to the effective working of the process. The cyanide liquor flowing away from the plant varies in strength from 2½ to 3 lb. of ammonium sulphocyanide per gallon, and (after conversion to calcium sulphocyanide) it may be concentrated to any desired strength.

The Davis-Neill Prussiate Process

The Davis-Neill process is one of comparatively recent introduction, and is in operation, notably, at the Linacre works of the Liverpool Gas Company. The hydrocyanic acid is extracted from the gas by washing with a solution of ferrous carbonate and soda. The first step in the process is the preparation of the ferrous carbonate, which is made by mixing copperas (sulphate of iron) with ordinary soda ash (carbonate of soda)—

$$FeSO_4+Na_2CO_3=FeCO_3+Na_2SO_4.$$

The mixture of ferrous carbonate and sodium sulphate is then passed through the first filter-press, in which the ferrous carbonate is retained as cakes. After thorough washing with clean water the cakes are removed to a second mixing tank or agitator, where they are intermixed with a further quantity of soda ash. The resulting cream is then run into the first bay of any suitable washer-scrubber. On meeting with the gas the iron carbonate is converted into sulphide by the action of the sulphuretted hydrogen in the crude gas, whilst the hydrocyanic acid combines with the sulphide in the presence of sodium carbonate to form sodium ferrocyanide—

(*a*) $FeCO_3+SH_2=FeS+CO_2+H_2O.$

(*b*) $FeS+2Na_2CO_3+6HCN=Na_4Fe(CN)_6+H_2S+2CO_2+2H_2O.$

In addition to sodium ferrocyanide certain quantities of other compounds, such as sodium and ammonium ferrous-ferrocyanide, are formed. For this reason the liquor undergoes further treatment, so that the whole of the cyanide may be recovered as a soluble prussiate. Leaving the washer-scrubber the liquor passes through a preliminary heater and then enters a still in which it meets with a strong solution of caustic soda. In this way the sodium ferrous-ferrocyanide is converted into sodium ferrocyanide as required—

$$Na_2Fe_2(CN)_6+2NaOH=Na_4Fe(CN)_6+Fe(OH)_2.$$

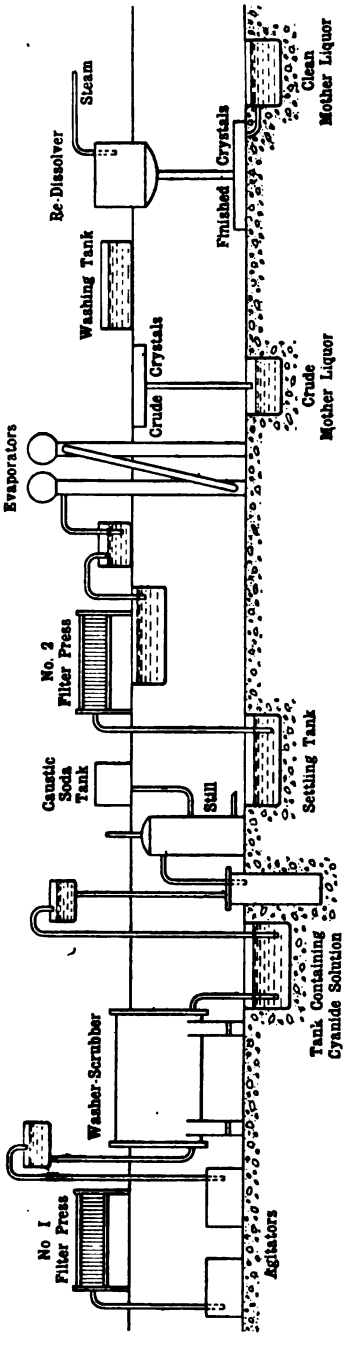


FIG. 256.—THE DAVIS-NEILL CYANIDE PROCESS.

The liquor obtained is then pumped through filter-press No. 2, in which any mud (chiefly consisting of iron sulphide) is retained. The cyanide solution, consisting in the main of prussiate of soda, but containing a small proportion of carbonate of soda, is then passed through an evaporator, and is finally recovered as yellow prussiate crystals. These crystals are afterwards washed with mother liquor from the finished crystallizing tanks, for the purpose of removing any impurities such as soda and sulphocyanides. The washed crystals are then treated in a re-dissolver, where the liquor they form is boiled for about 15 hours, before being run off to the finished crystallizing tanks. Slow cooling is desirable at this stage, otherwise small crystals will be formed.

Bueb's Process

The process of Dr. J. Bueb is one which has been used fairly widely, particularly on the Continent. The apparatus made use of is a washer-scrubber, in which a solution of ferrous sulphate dissolved in ammoniacal liquor is employed for washing the gas. The sulphate is converted into iron sulphide by the sulphuretted hydrogen in the crude gas—

$$FeSO_4+H_2S+2NH_3=FeS+(NH_4)_2SO_4.$$

The sulphide, ammonia, and hydrocyanic acid then combine to form—

(*a*) Ammonium ferrocyanide—

$$FeS+6NH_3+6HCN=(NH_4)_4Fe(CN)_6+(NH_4)_2S.$$

(*b*) Cyanide of iron—

$$FeS+2NH_3+2HCN=Fe(CN)_2+(NH_4)_2S.$$

(*c*) Ammonium ferrous-ferrocyanide—

$$2FeS+6NH_3+6HCN=(NH_4)_2Fe_2(CN)_6+2(NH_4)_2S.$$

By treating with lime the insoluble ferrous-ferrocyanide is converted into a soluble calcium ferrocyanide—

$$(NH_4)_2Fe_2(CN)_6+2Ca(OH)_2=2NH_4OH+Ca_2Fe(CN)_6+Fe(OH)_2.$$

The free ammonia may then be distilled off by means of steam and recovered, whilst the residual liquor is mixed with the required quantity of sodium carbonate or hydrate, when sodium ferrocyanide results—

$$Ca_2Fe(CN)_6+2Na_2CO_3=Na_4Fe(CN)_6+2CaCO_3.$$

Ciselet and Deguide, in their process, first bring the gas into contact with ferric hydrate, which absorbs the sulphuretted hydrogen and hydrocyanic acid in the gas. The sulphur and cyanogen are precipitated in the form of iron sulphide and iron cyanide. The iron sulphide is then regenerated to the hydrate by means of an air blast, the sulphur being precipitated in the free form. After regeneration, the ferric-hydrate solution is treated with sulphuric acid, which renders the iron soluble whilst the sulphur and cyanogen remain insoluble. The two last-named can then be separated with an alkaline solution, which dissolves the cyanogen compounds

and forms alkaline ferrocyanides. Meanwhile, the free sulphur remains insoluble and can be filtered out.

South Metropolitan Gas Company's Process

The South Metropolitan Gas Company have introduced a process by means of which the cyanogen in the gas is recovered as hydrocyanic acid. The crude gas is washed with a solution of ferrous sulphate, the resulting liquor being treated with an ammonium salt and boiled with lime, so that a double cyanide—*i.e.*, calcium-ammonium ferrocyanide, $Ca(NH_4)_2Fe(CN)_6$—is formed. The acid radicle, namely, the hydrocyanic acid portion of the salt, is unaffected by the action of sulphuric acid, whilst the remainder is converted into ferrous ammonium ferrocyanide and calcium sulphate. In this way a means is provided for separating out the cyanogen as hydrocyanic acid and recovering it as such.

EXTRACTION FROM SPENT OXIDE

It has already been pointed out that when no special means is provided for the recovery of cyanogen from the gas nearly the whole of it is arrested by the oxide of iron in the dry purifiers. Owing to the possibility of revivifying the iron sulphide, and, accordingly, the utilization of the mass over and over again, considerable quantities of cyanogen may have been collected by the time the material is finally spent. There are numerous processes for the recovery of cyanogen from oxide, but, in general, they may be classified into two distinct groups, namely—

(*a*) Those in which the free sulphur is first extracted by means of some solvent such as carbon disulphide.

(*b*) Those in which the spent material is straightway treated for the recovery of the cyanogen.

The processes in the latter group are those chiefly in use, and consist, in the main, of the lixiviation of the material for the removal of the soluble salts, such as ammonia and the sulphocyanides. The insoluble cyanide salts then undergo treatment to convert them into soluble compounds, and finally the whole of the cyanogen is recovered as potassium ferrocyanide.

Lixiviation of the material is carried out in tanks in which, by any suitable arrangement, the oxide is thoroughly washed with water. The liquor thus obtained is treated in the ordinary manner with lime for the recovery of ammonia, a certain amount of calcium sulphocyanide being formed by the action of the lime. The next stage is the recovery of the insoluble ferrocyanides by treating them with lime or other alkali. This process is now frequently carried out in a mechanical stirring apparatus. The material is led, together with the dilute liquid obtained in the first stage of the process, into a boiler, and the mass is heated with steam and thoroughly intermixed by means of the stirring apparatus. The sludge obtained is then caused to flow to a filter-press in which the cyanide solution is separated. The cakes from the press are afterwards thoroughly pulverized and sifted, mixed with lime, and finally treated again in a stirring tank. The resultant liquor contains chiefly calcium ferrocyanide and some calcium sulphocyanide.

The next step is to precipitate the ferrocyanides from the solution, so that they may be recovered. This may be carried out in several ways, that is by iron, ammonia, or potassium salts. When utilizing ammonia the cyanide solution is treated with hydrochloric acid, the acid being added until the mixture is acid. In this way a double salt, calcium-ammonium ferrocyanide, is obtained—

$$Ca_2Fe(CN)_6+2NH_4Cl=Ca(NH_4)_2Fe(CN)_6+CaCl_2.$$

The double cyanide may then be admixed with a further quantity of lime, when a pure calcium ferrocyanide results—

$$Ca(NH_4)_2Fe(CN)_6+Ca(OH)_2=Ca_2Fe(CN)_6+2NH_3+2H_2O.$$

Finally, the calcium ferrocyanide may be converted into potassium ferrocyanide.

When potassium chloride is used for precipitation a double salt is again formed, in the first instance—

$$Ca_2Fe(CN)_6+2KCl=CaK_2Fe(CN)_6+CaCl_2.$$

This salt is then separated by filtration, washed, and treated with potassium carbonate, when potassium ferrocyanide results—

$$CaK_2Fe(CN)_6+K_2CO_3=CaCO_3+K_4Fe(CN)_6.$$

CONVERSION OF CYANIDES INTO AMMONIA

Although the hydrocyanic acid in coal gas may now be recovered by comparatively simple means, universal extraction is not altogether possible, owing to the limited demand for the product. For this reason renewed attempts have been made to overcome the market difficulty by converting the cyanogen into ammonia, for which there is always a steady demand. The idea is by no means novel, for mention is made of the process in scientific literature published some seventy-five years ago, whilst a patent specification for another means was filed in 1882.

As regards more recent investigation into the possibility of converting cyanides into ammonia, mention must first be made of the work of Henri Burgevin and Burkheiser. The former conducted his experiments with the cyanide compounds present in spent purifying material. Ammonia can be extracted from these by dry distillation, or by treatment with steam under pressure, followed by the use of alkalies, or by employing a mixture of soda and lime. Such processes are, however, unsatisfactory on a manufacturing scale, and Burgevin has overcome the drawbacks of using a costly reagent, soda; whilst by his method the incomplete nature of the reaction is avoided. The employment of lime alone is sufficient, while a recovery of practically the whole of the nitrogen is claimed. According to the patent specification, when cyanide compounds are recovered by means of raw purifying material, the latter must first be treated with some suitable solvent (such as carbon disulphide) in order to ensure complete absence of free sulphur. The residue is then thoroughly intermixed with slaked lime in the correct proportions, and the two compounds are caused to react at red heat. The reaction is entirely completed at this temperature, and the gaseous mixture liberated will consist chiefly of free ammonia. If care is taken to see that the mixture is homogeneous, it is said that

at least 95 per cent. of the original nitrogen in the cyanide compounds can be recovered in the form of ammonia. The approximate quantity of lime required for effecting the transformation is ten times (by weight) of the amount of nitrogen contained in the original material to be treated; and it is suggested that the ammonia should be converted into ammonium sulphate by passing the gas through a seal of sulphuric acid. The method also allows for the partial conversion, into ammonia of the small proportion of nitrogen compounds, other than cyanides, which is to be found in purifying materials.

The most recent process, which is based on original lines, is that of the South Metropolitan Gas Company. Although detailed particulars are not available, it appears to consist essentially of treating the recovered compound (in the form of a sulphocyanide) with an excess of sulphuric acid at some definite temperature, when ammonia, carbon oxysulphide, and acid sulphate of ammonia should result.

It is well known that the action of sulphuric acid upon potassium sulphocyanide gives thiocyanic acid—

$$KCNS+H_2SO_4=HCNS+KHSO_4,$$

the latter then being decomposed by water, in the presence of an excess of sulphuric acid, into carbon oxysulphide and ammonia—

$$HCNS+H_2O=NH_3+COS,$$

the ammonia, at the same time, combining with the sulphuric acid.

In the case of ammonium sulphocyanide, the two reactions would be very similar in character; ammonium bisulphate resulting in the first place—

$$NH_4SCN+H_2SO_4=HCNS+NH_4HSO_4.$$

The second reaction for conversion into ammonia is then similar to that given above. The process would appear to be somewhat delicate, owing to the fact that, if the working temperature is carried too high, the cyanogen is likely to be volatilized, and lost in the form of thiocyanic acid. Accordingly, temperature regulation plays an important part; but, working under good conditions, a conversion of 98 per cent. of the total nitrogen into ammonia should be possible. In addition to carbon oxysulphide being evolved, it seems probable that some sulphuretted hydrogen results from the reaction. This is most likely, owing to the fact that carbon oxysulphide is freely absorbed by ammonia, and, on evaporation, yields sulphuretted hydrogen, or possibly urea (*see* page 380). It is feasible, too, that a portion of the carbon oxysulphide may split up in the presence of water and steam, and yield carbon dioxide and sulphuretted hydrogen, according to the equation—

$$COS+H_2O=CO_2+H_2S.$$

THE LIME METHOD

A second successful method is based on lines somewhat similar to those of Burgevin, and is particularly applicable in cases where hydrocyanic acid is recovered in the ammonium, and finally calcium, sulphocyanide form, as is the case in the

polysulphide cyanide process. The calcium sulphocyanide produced is first evaporated to dryness, and is then mixed with an excess of slaked lime, and subjected to a moderate heat of not less than 1,CC0° Fahr. Under the influence of this temperature the cyanides are broken up in the presence of steam, and yield ammonia and carbon oxysulphide. The ammonia may be drawn off to an absorption vessel containing sulphuric acid, while the carbon oxysulphide will be mostly removed by the excess of lime. The manner in which the lime and cyanide are admixed is of no little importance for the effective working of the process. With regard to the actual reactions taking place, these appear to be on lines such as the following—

(*a*) $Ca(CNS)_2+Ca(OH)_2+2H_2O=2NH_3+COS+CaCO_3+CaS.$

The precaution is taken of removing the carbon oxysulphide evolved by arranging for a layer of lime 2 or 3 inches deep to be placed over the mixture in the heating chamber. The carbon oxysulphide is then removed as follows:—

(*b*) $COS+2Ca(OH)_2=CaS+CaCO_3+2H_2O.$

The removal of the carbon oxysulphide in this way is essential; for ammonia and this compound may combine, with the possible formation of urea, according to the following equation:—

$$COS+2NH_3=H_2S+CO(NH_2)_2.$$

So far as the respective merits of the two more modern processes are concerned, there is little to choose between them on the ground of efficiency—both giving a conversion of about 98 per cent. For a works having its own sulphuric acid plant, however, or in cases where supplies of acid can be readily obtained, the sulphuric acid method is undoubtedly to be preferred. In the lime method, use might conceivably be made of the waste heat from the retort benches, or one or two retorts could be set apart for the special cyanide purpose. Furthermore, if it was not desired to recover the evolved ammonia there and then, it could be passed into the foul main along with the gas, when, by absorption of sulphuretted hydrogen and carbonic acid, it would lighten the work of the ordinary purifying vessels.

From the financial standpoint there is nothing particularly alluring about the conversion of cyanides into ammonia. It must be remembered, however, that the indirect advantages accruing from the employment of a cyanogen plant are the chief recommendation of the process. As before stated, the universal extraction of cyanogen is scarcely feasible at the present time, owing to the restricted market for this residual, and the growing tendency to produce it by other means.

So far as the polysulphide process is concerned, the average cost of recovery is from 0·04*d.* to 0·05*d.* per lb., or about ¼*d.* per ton of coal carbonized. Assuming a yield of 5 lb. of calcium sulphocyanide per ton, it will be seen that if this sells at 1*d.* per lb. the net profit is in the neighbourhood of 4¾*d.* per ton of coal carbonized. Then, if this quantity of calcium sulphocyanide was further worked up into ammonia, it should give about 4¼ lb. of sulphate of ammonia, thus increasing the total yield

of sulphate from an average of 28 lb. per ton of coal to 32¼ lb. per ton, or by rather more than 15 per cent. With sulphate selling at 1¼*d.* per lb., the additional revenue from this source would be about 5½*d.*, against 4¾*d.* for cyanide.

TESTING COAL GAS FOR CYANOGEN

The gas to be tested for cyanogen is passed through two wash-bottles of about 250 to 300 c.c. capacity, each containing 100 c.c. of ammonium polysulphide solution (made by shaking up a 10 per cent. solution of ammonium sulphide with powdered sulphur). A little (say 10 grains) of powdered sulphur is also put into each wash-bottle, to ensure the presence of an excess. The gas should be passed through the wash-bottles at the rate of about 2 cubic feet per hour, and the test should, preferably, be continued for sixteen hours or more. The amount of gas passed should be determined by a small meter. At the conclusion of the test, the contents of the wash-bottles are transferred to a litre flask, and, with the washings made up to 1,000 c.c., 50 c.c. (or such aliquot portion as represents from 1 to 2 cubic feet of gas) are transferred to a small porcelain basin, and evaporated on the water-bath down to about 10 c.c. Some hot water and a little moist carbonate of lead are added (to remove all sulphides), and the whole filtered. The filtrate is slightly acidified with dilute sulphuric acid, a solution of sulphurous acid added until the liquor smells strongly of SO_2, and then a weak solution of pure sulphate of copper in slight excess, the whole heated a short time on the water-bath, filtered hot, and washed.

The filter containing the cuprous sulphocyanide is transferred to a beaker (preferably the one in which the precipitation took place, as small portions of the precipitate may be adhering to the glass). From 25 to 50 c.c. of normal caustic soda free from chlorides are added, and about 100 c.c. of boiling water, and the whole heated on the water-bath, with frequent stirring, until the cuprous oxide becomes sufficiently granular to filter. Filter while still hot, wash well with hot water, and allow the combined filtrate and washings to cool. Acidify slightly with pure dilute nitric acid, add a few drops of ferric sulphate solution, and titrate with decinormal silver nitrate until the colour disappears. Towards the end of the titration add a few more drops of ferric sulphate to increase the distinctness of the end reaction.

Example. 23·5 cubic feet of gas were passed through the wash-bottles in twenty-four hours, and the contents were made up to 1,000 c.c., of which 50 c.c. (representing 1·175 cubic feet of gas) were taken. After proceeding as above 32·7 c.c. of decinormal silver nitrate were required for titration—

1 c.c. of silver nitrate = 0·0076 gramme of ammonium sulphocyanide.

∴ 32·7 „ „ = 0·2485 „ „ „ „

i.e. 1·175 cubic feet of gas contain 0·2485 gramme of ammonium sulphocyanide,

or 100 cubic feet of gas contain 21·1 grammes of ammonium sulphocyanide.

There are 15·43 grains in 1 gramme, therefore 21·1 × 15·43 = 325·5 grains of ammonium sulphocyanide per 100 cubic feet.

The molecular weight of ammonium sulphocyanide is 76, and that of hydrocyanic acid 27, so that $325{\cdot}5 \times \frac{27}{76} = 115{\cdot}6$ grains HCN per 100 cubic feet.

The above test is usually made use of only when sulphocyanide processes are in operation. When ferrocyanide plants are employed the following method is preferable—

A 30 per cent. solution of caustic soda or caustic potash is mixed with a 12 per cent. solution of ferrous sulphate in the proportion of 5 to 1. The mixture is poured into three Woulffe's bottles, and gas is passed through at the rate of 1 cubic foot per hour. After about 10 cubic feet of gas have been passed the mixture (collected from the three Woulffe's bottles) is washed into a graduated flask, and a portion is taken for analysis. The mixture is boiled until free from ammonia, and is then filtered. The filter paper is washed with hot water until a few c.c. on being acidified with hydrochloric acid give no blue colouration on the addition of ferric chloride. The filtrate and washings are acidified with hydrochloric acid and the cyanogen is precipitated with ferric chloride, as Prussian blue. The whole is then poured into a tared filter paper and well washed with hot water until the filtrate is free from iron salts. The filter paper and contents are then dried and weighed.

Example.—10 cubic feet of gas were passed through the caustic soda and ferrous sulphate mixture. The mixture washings were then made up to 500 c.c., of which 100 c.c. were taken for analysis, *i.e.* equal to 2 cubic feet of gas. After treatment the amount of Prussian blue obtained was 4 grains.

860 parts of Prussian blue contain 468 parts of cyanogen (CN); therefore,

4 grains will contain $\frac{4 \times 468}{860} = 2{\cdot}18$ grains of cyanogen from 2 cubic feet of gas,

or $2{\cdot}18 \times 50$ grains $= 109$ grains per 100 cubic feet of gas.

CHAPTER XVI

THE DRY PURIFICATION OF COAL GAS

THE theory and practice of the dry purification of coal gas, the chemical changes involved, and the construction and working of the necessary apparatus are subjects which, if dealt with in their entirety, would justly claim a complete volume to themselves. For this reason it is impossible, within the limits of a single chapter, to touch upon more than the salient features of the process and upon those sections of it which are of direct interest to the gas engineer.

In some instances, nowadays, purification is carried to extreme lengths, in order that a gas of exceptional purity may be supplied to the consumer. In the majority of cases, however, the gas is treated in such a manner that it may satisfy the usual statutory requirements, whilst no attempt is made to produce a super-quality.

At this stage of the manufacturing process the impurities present in the gas may be set down as follows—

Ammonia	nil to 1·5 grains per 100 cubic feet.
Sulphuretted hydrogen	500 to 800 „ „ „ „
Sulphur compounds (other than SH_2)	35 to 50 „ „ „ „
Hydrocyanic acid	50 to 70 „ „ „ „
Carbon dioxide	750 to 1,150 „ „ „ „.

Of these, sulphuretted hydrogen must, in accordance with the requirements of the law, be removed to the merest trace. This, however, is not the case with the remaining four compounds.

Until the year 1905 a certain limit was placed (in London and many provincial towns) on the quantity of sulphur compounds present, with the result that special treatment was accorded the gas for the removal of these compounds before it left for the distribution area. The limits imposed at that time precluded, during the winter months, a greater quantity of sulphur compounds than 22 grains per 100 cubic feet of gas, whilst during the summer months the limit was reduced to 17 grains. The greater portion of the cyanogen is extracted during the passage of the gas through the oxide purifiers, unless, of course, a special plant for its recovery has been previously interposed. Carbon dioxide, as previously explained, is not strictly an impurity but a diluent. There are no statutory restrictions as to its presence in the finished gas, and its effect is chiefly felt in the direction of illuminating and calorific power tests (*see* page 394).

Of the impurities named, the gas in normal instances contains, when distributed, the following quantities—

Sulphuretted hydrogen	nil.
Ammonia	nil.
Sulphur compounds (other than SH_2)	35 to 50 grains per 100 cubic feet.
Hydrocyanic acid	nil to 10 „ „ „ „
Carbon dioxide	750 to 1,150 „ „ „ „

Where a proportion of carburetted water gas is added to the coal gas the mixture (owing to the lower sulphur content of water gas) contains a smaller percentage of sulphur impurities than does a neat coal gas. Purified carburetted water gas contains on an average from 10 to 15 grains of sulphur compounds per 100 cubic feet.

The abolition of the sulphur clauses in 1905 did much to simplify the process of gas purification, in that lime as an absorptive medium is now largely dispensed with. The somewhat erratic operation of this material and the uncertainty of its working were such as to prove a constant anxiety to the works manager. In addition, considerable expense was incurred in order to effect the removal of an impurity present in quantities so small as to render it practically innocuous. To-day oxide purification for the removal of sulphuretted hydrogen is of primary interest to the gas engineer, although the use of lime has been by no means universally discarded.

REMOVAL OF SULPHURETTED HYDROGEN

The elimination from the gas of this impurity presents no great difficulties, but the manner in which the necessary plant is operated varies considerably with the tastes of the engineer. Of the original quantity of sulphuretted hydrogen the bulk remains in the gas after the latter has passed the washers and scrubbers, and is almost invariably removed by causing the gas to pass in contact with layers of special material in a moist condition. The chief materials employed for sulphuretted hydrogen removal have, in the past, been hydrated lime, hydrated oxide of iron, and manganese dioxide in the form of Weldon mud. Natural ferric oxide (bog-ore) is still largely made use of, but in recent years there has been a tendency to turn to various artificial preparations, which may be obtained more cheaply and which, in many cases, have increased activity as compared with bog-ore.

Natural Oxide of Iron

Natural oxide of iron, or bog-ore, occurs in peaty deposits in large quantities in Ireland, Holland, and Belgium, also to a limited extent in England, chiefly in the neighbourhood of Westbury (Wiltshire). In its natural form the ore contains from 50 to 60 per cent. of water, and between 30 to 35 per cent. of ferric oxide (Fe_2O_3). In addition to iron compounds the virgin material contains about 15 to 25 per cent. of inert matter, consisting chiefly of vegetable substances and silica. In the dried state the analysis of an oxide of good quality will vary between the following limits—

Hydrated ferric oxide (Fe_2O_3,H_2O)	60 to 65 per cent.
Organic matter	15 to 25 „
Silica	3 to 6 „
Alumina	1 „

The silica content of a natural oxide varies very much, in accordance with the district from which it is taken. Best Dutch material seldom contains more than 4 to 5 per cent. Belgian oxide may contain from 10 to 12 per cent., whilst oxide occurring in this country has been known to contain so much as 20 per cent. of silica and alumina. The proportion of silica present has some considerable effect on the relative density of the various oxides. In general the following figures may be taken as representing the volume equivalent to 1 ton—

Dutch oxide	45 cubic feet per ton.
Belgian oxide	40 „ „ „
Wiltshire oxide	35 „ „ „

The active material in bog-ore is not the actual oxide, but the oxide plus a certain amount of water of combination, *i.e.* a hydrated ferric oxide, Fe_2O_3, H_2O. In addition to this moisture the material as used should contain a further quantity of water, usually from 20 to 30 per cent. For effective working the moisture should never be less than the lower limit given. In practice it is generally realized that the material should be in such a state as regards moisture that it will, when pressed in the hand, bind like snow. In common with natural oxides the artificial varieties are employed with a similar degree of moisture. The made-up material is usually more active than the natural product, owing to a rather higher content of ferric hydrate (which may reach so much as 70 to 75 per cent.), and on account of the elimination of vegetable matter.

When foul gas containing sulphuretted hydrogen is passed through a vessel filled with oxide of iron the sulphuretted hydrogen alone is extracted, the oxide having no affinity for carbon disulphide or carbon dioxide. The absorption of the sulphuretted hydrogen occurs in two distinct ways, which may be shown as follows—

(1) Fe_2O_3, $H_2O + 3H_2S = Fe_2S_3 + 4H_2O$ (ferric sulphide).

(2) Fe_2O_3, $H_2O + 3H_2S = 2FeS + S + 4H_2O$ (ferrous sulphide).

It will be noted that in the first instance ferric sulphide is formed, whilst in the alternative equation ferrous sulphide and free sulphur result.

After a time the material ceases to absorb sulphuretted hydrogen, but can be returned to a state of activity by the process known as "revivification." For this purpose it is removed from the purifying boxes, spread out in a thin layer, turned over, and exposed to the action of the oxygen in the atmosphere. By this means the iron sulphides are oxidized and assume their original character with the deposition of free sulphur—

(*a*) $2Fe_2S_3 + 3O_2 + 2H_2O = 2Fe_2O_3,H_2O + 3S_2$.

(*b*) $4FeS + 3O_2 + 2H_2O = 2Fe_2O_3,H_2O + 2S_2$.

The material, together with the free sulphur, is then returned to the purifier, when precisely the same reactions recur. Revivification may then be carried out

again, and the oxide repeatedly returned to the purifiers until it contains upwards of 55 or 60 per cent. of sulphur, beyond which figure it will not be found economical to go.

So far as the other mediums employed for the removal of sulphuretted hydrogen are concerned, Weldon mud, a by-product of the bleaching industry, owes its activity to the presence of manganese dioxide. The reactions occurring are very similar to those appertaining to oxide of iron, a manganese sulphide capable of regeneration resulting. In many respects Weldon mud is superior to oxide of iron for purification purposes. It cannot, however, be obtained now owing to the abandonment of the old Weldon chlorine process. The chief advantages which may be claimed for the material are increased absorptive activity as compared with oxide, whilst owing to the possibility of revivifying it *in situ* it is possible to work up the spent material to a high sulphur percentage before removing it from the purifier. Owing to its sensitive nature Weldon mud was, in the days of universal lime purification, particularly suited for use in " catch boxes."

Of present-day preparations the material known as " Lux " has met with some considerable success, owing to the sensitive nature of its operation. " Lux " is obtained from bauxite (*i.e.* ferric aluminate), which is powdered, mixed with a definite proportion of soda, and raised to a red heat. This results in the formation of sodium aluminate and sodium ferrate. The mass consisting of these two sodium compounds is then treated with water, when the sodium aluminate dissolves out and the ferrate is decomposed and forms a colloidal hydrated oxide.

In the condition as delivered for use " Lux " contains about 55 per cent. of ferric oxide and 20 per cent. of alkaline salts. In many cases it is desirable to mix a certain proportion of sawdust with the material as it is received, the usual ratio being 3 parts of " Lux " to 1 part of sawdust. It is said by some that with " Lux " the absorption of SH_2 takes place more rapidly than with bog-ore, owing to the fact that the ferric hydrate is separated out in a finely divided state during the manufacture of the material. In addition, it is claimed that a greater percentage of sulphur may be obtained before the material is finally spent; but some trouble may be experienced from firing.

Other preparations such as " Ferrox " and " Brownox " contain a higher proportion of ferric hydrate than is the case with the natural bog-ore. This accounts for their somewhat vigorous action, although in their preparation the addition of other ingredients adds to their efficiency. Broadly speaking they may be said to result from burnt spent oxide, which is obtained from sulphuric acid works, rendered active by special treatment. This treatment varies with the type of material, but in one instance it consists almost solely of grinding the burnt product in a disintegrator with the addition of a definite proportion of soda ash and sawdust. A product known as Laming's mass was at one time a great favourite in France, Spain, Italy and the East. This consists of sawdust mixed with lime and wetted with a solution of sulphate of iron.

Purifying material in this country is generally purchased on the basis of analysis, *i.e.* so much per ton for a certain percentage of ferric oxide. The spent material is

sold in accordance with its sulphur content, *i.e.* so many pence for each unit of sulphur. To explain this it may be assumed that a spent oxide contains 50 per cent. of free sulphur, *i.e.* 50 units per ton. If the price per unit is 5*d.*, the value of the oxide is (50 × 5*d.*) = 250*d.* or 20*s.* 10*d.* per ton. Small works frequently obtain their oxide on a loan basis, paying (say) a penny per ton of coal carbonized, and returning the spent material, when it has reached a certain sulphur content, to the supplier. As bog-ore and other purifying materials are frequently bought subject to certain conditions—particularly with regard to their content of ferric oxide or ferric hydrate—the following contract form, which may be adopted as a standard, has been included, in the belief that it may prove of some value to gas engineers having the purchase of oxide in view.

SPECIFICATION AND FORM OF TENDER FOR OXIDE OF IRON

Description—The tender must state the description of material to be supplied.

Quantity—The quantity of material required is . . . tons.

Moisture—The moisture is not to exceed 50 per cent. by continued heating at 212° Fahr.

Ferric Oxide—The quantity of ferric oxide (*i.e.* Fe_2O_3, inclusive of Fe_2O_3 as FeO) is to be not less than 25 per cent. in the material (in the natural state).

Price—The tender is to be at a rate per unit of ferric oxide (Fe_2O_3, inclusive of Fe_2O_3 as FeO) per ton in the condition as supplied.

Delivery—(As required).

Notice of Arrival—A week's notice of probable time of delivery should be given by seller to buyer.

Analysis—Within ten days of each delivery the seller and buyer shall exchange results of their respective analyses of sample. Should these results differ in the percentage of ferric oxide by not more than 2 per cent. the mean shall be taken, but if the difference exceeds 2 per cent. then a remaining sealed portion of the sample shall be submitted to an independent analyst (nominated by the buyer and agreed to by the seller), whose decision shall be final. The cost of such analysis shall be borne by the party whose result is the more divergent.

Forfeiture—Should the analysis of the sample of any delivery show that the conditions herein specified are not complied with, then it shall be at the option of the buyer to make such deductions from the account as shall compensate him for loss arising from the non-compliance.

Failure of Delivery—In the event of any failure on the part of the seller to deliver the material of stipulated quality and otherwise in accordance herewith, the buyer may procure a corresponding quantity of material from other parties, and any loss incurred by the buyer in so doing is to be borne by the seller, and to be deducted from any sum due to him, or, in the event of no such sum being due, is to be recoverable by action as if on a simple contract debt.

Payment—Payment shall be made within fourteen days of agreement as to analysis, less 2½ per cent.

Arbitration—Any dispute arising out of or in connexion with this contract is

to be settled by arbitration by two arbitrators (one to be named by each party) and an umpire, in manner provided by the Arbitration Act of 1889 or any statutory modification thereof.

THE EFFECTIVE WORKING OF PURIFIERS

It is seldom advisable to put bog-ore into operation in the state in which it arrives, for some difficulty may be experienced in getting the material to commence working. When trouble is experienced in this way, the admixture of a small proportion of material which has previously been in use will generally overcome the difficulty.

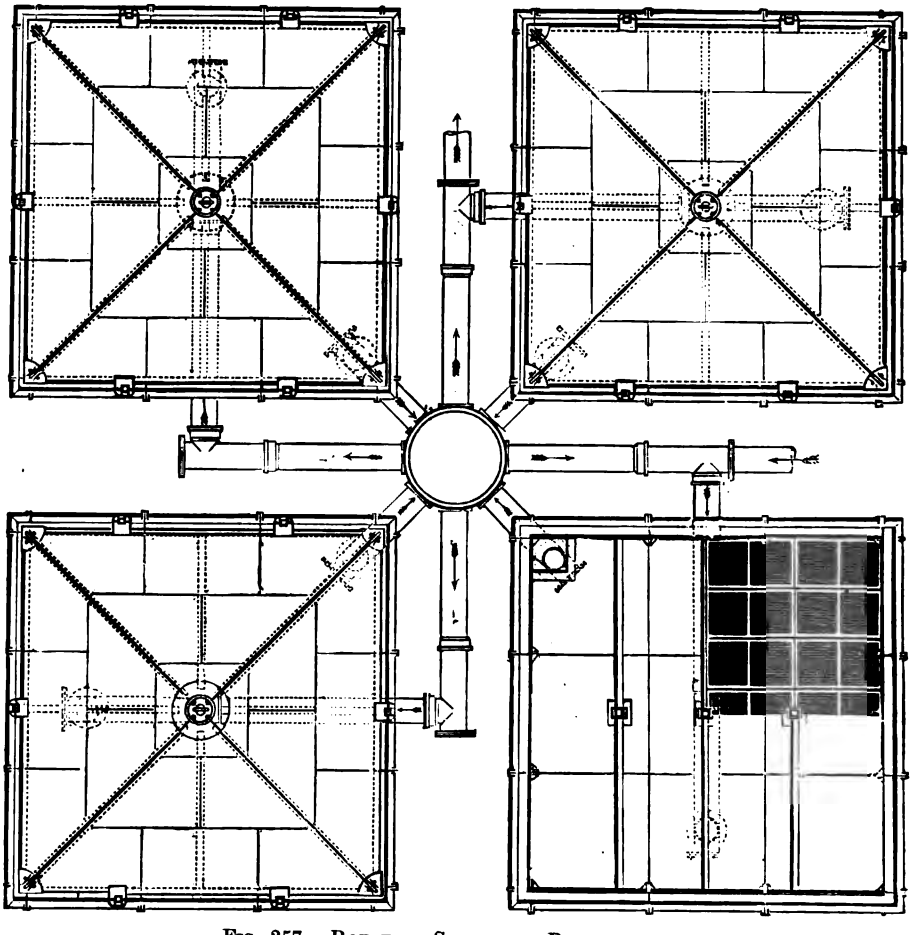


FIG. 257.—ROTATION SYSTEM OF PURIFICATION.

Present-day systems of purification may be classified under two headings, namely—

(*a*) Series purification. (*b*) Rotation purification.

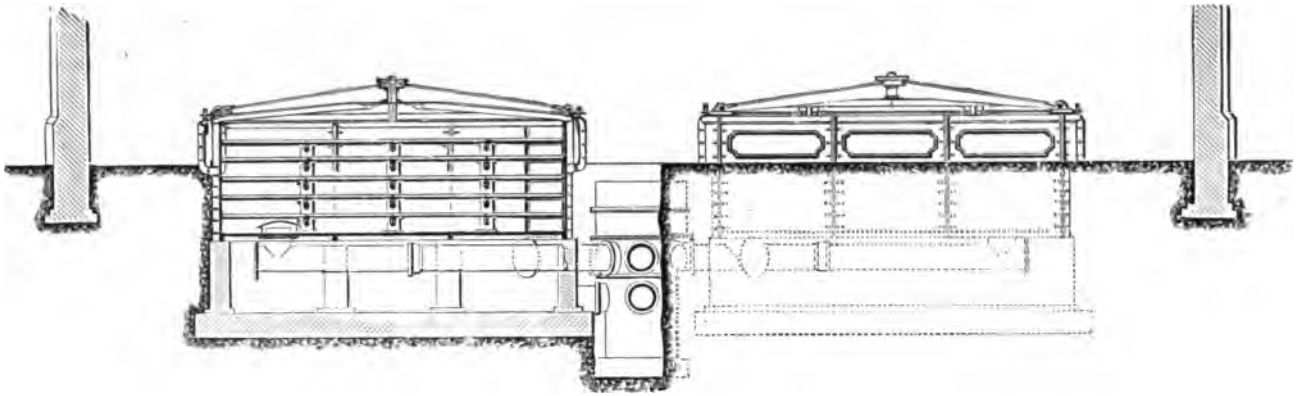


FIG. 258.—SECTION THROUGH PURIFIERS AND CENTRE VALVE.

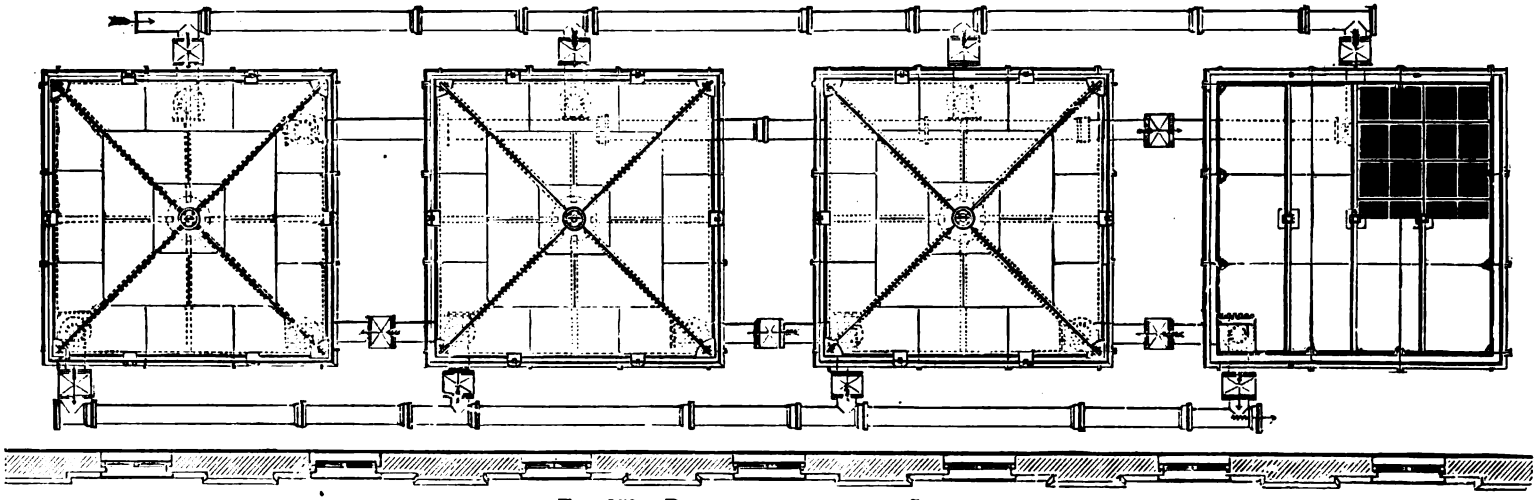


FIG. 259.—PURIFIERS ARRANGED IN SERIES.

The difference between the two systems is in reality a constructional one, and depends merely upon whether a set of purifiers is arranged around a centre valve, as shown in Fig. 257, or in a line, with a number of single valves, as seen in Fig. 259. For the operation of the rotation system it is not necessary that the four purifiers should be set one at each corner of a square, although this arrangement is the most convenient. With oxide purification the *modus operandi* usually adopted is that of having three of the four boxes in action at a time; that is, gas is passing first through the first box or "taker," then through the second, and lastly through the third, by which time it is wholly deprived of sulphuretted hydrogen. After a time the oxide in the first box becomes "fouled" and useless for the further extraction of SH_2 until the material is revivified. No. 4 box is then put into action and No. 1 box is shut off, so that the original second box now becomes first "taker." In the meantime No. 1 box is thrown out, revivified and remade, and is then ready for action once more as the final box when required. Thus we get—

First series → 1 → 2 → 3, 4 off.
Second ,, → 2 → 3 → 4, 1 off.
Third ,, → 3 → 4 → 1, 2 off.
Fourth ,, → 4 → 1 → 2, 3 off.

In this way each purifier comes in for an "off" period, so that it may be dealt with when it has become "fouled." The system of working as described applies to purifiers arranged either in series or around a centre valve. It should be mentioned that in the majority of works, with the exception of those of small dimensions, a further

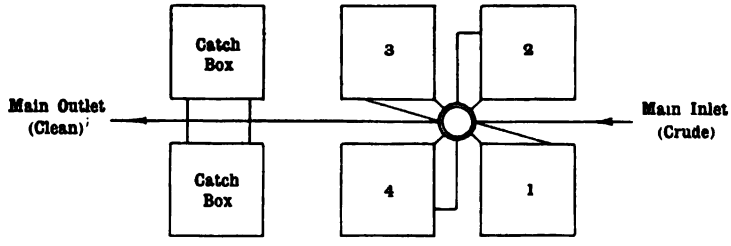


FIG. 260.—ROTATION SYSTEM WITH CATCH-BOXES.

safeguard against the possibility of sulphuretted hydrogen getting through to the district mains is provided for by the insertion of two "catch-boxes," as shown in Fig. 260.

Within recent years a new and effective method of arranging the series of purifiers has come into operation, and is known as "backward rotation." It differs essentially from the ordinary system in that when a box operating first in the series becomes fouled the clean box is placed first in position instead of last. Thus if four purifiers are operating in series, we shall have—

First series → 1 → 2 → 3 → 4
Second ,, → 4 → 1 → 2 → 3
Third ,, → 3 → 4 → 1 → 2, and so on.

By the adoption of this method it is claimed that where "catch-boxes" have previously been in use they may be dispensed with, although such a procedure would seem to be attended by some risk. The author finds that where a works has outgrown its purifying capacity the method is particularly suitable, and instances are known where the cubical capacity available is so low as 0·25 cubic feet per 1,000 cubic feet of gas per diem, and yet no trouble is experienced.

Another method which has found some favour is that known as "forward rotation." That is to say, when the first "taker" becomes fouled it is placed at the end of the series, thus—

First series → 1 → 2 → 3 → 4
Second „ → 2 → 3 → 4 → 1, etc.

When working in this manner it would seem essential that "catch-boxes" should be used, owing to the tendency of the final purifier to throw off a certain amount of sulphuretted hydrogen. In fact it may be said that in all cases the introduction of "catch-boxes," although theoretically unnecessary, is a wise precaution against sudden eventualities.

THE ADMISSION OF AIR

Oxide of iron is generally used in the purifiers in layers varying from 8 inches to 10 inches in depth, although in some cases it is still customary to adhere to deeper tiers of about 30 inches. The last-named, however, frequently give rise to excessive back pressure, and are not to be advised in the ordinary way. A space of not less than 2 inches should always be allowed between the top surface of one layer and the underneath surface of the grid above it. Oxide as it becomes fouled increases in bulk—hence this precaution.

Partial revivification *in situ* is almost always arranged for nowadays, the small quantity of air admitted during the process considerably adding to the working life of the material. Care has, of course, to be exercised with regard to the quantity of air introduced. The usual allowance is 2½ per cent. for every 1 per cent. of sulphuretted hydrogen present, and as the SH_2 amounts in normal cases to about ½ per cent., the theoretical quantity of air required is about 1 per cent. Some engineers arrange for 15 cubic feet of air per 1,000 cubic feet of gas. The admission of air may be arranged for in two ways. It may be sucked in from the atmosphere through a pipe on the inlet or vacuum side of the exhauster (in which case the air should be drawn through a meter so that its volume may be measured), or it may be injected direct into the mains leading to the purifiers by means of an ordinary steam injector. An effective means of arranging an injector system is shown in Fig. 261. On the larger works an injector may be fitted to the inlet of each purifier, whilst in small works a run of two or three hours' duration every day should answer the purpose. When air is sucked through from the inlet side of the exhauster it is advisable to introduce some safeguard in case sudden pressure might arise from any cause. The safety seal shown in Fig. 262 is simple and convenient. It consists of a cast-iron box about 12 inches square by 4 inches deep, with a flat cover securely jointed. Water should be poured in at B until it overflows from the bib-cock C. The outlet

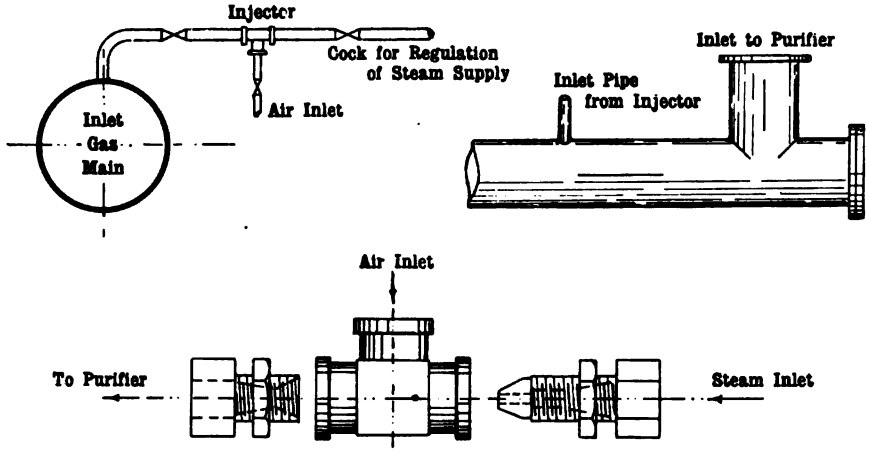


FIG. 261.—AIR INJECTOR FOR DRY PURIFIERS, SHOWING METHOD OF CONNECTING UP.

of the meter is connected to A, and the service D leads to the gas main. The base of the seal-pipe A, which is screwed, is so adjusted that it dips below the surface of the water to the depth of about an inch. In the event of back-pressure the water will be depressed and rise in the pipe A, which should not be less than 24 inches to 30 inches in height.

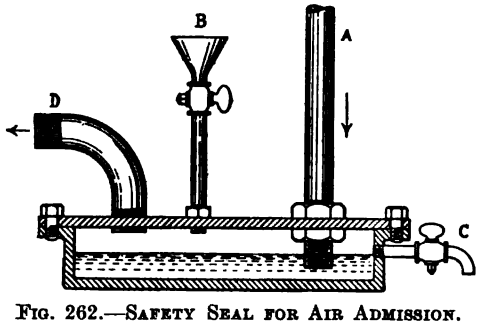


FIG. 262.—SAFETY SEAL FOR AIR ADMISSION.

It should be borne in mind that most coal gas will contain a certain amount of oxygen, and the quantity varies to some considerable extent. It is important, therefore, to test the gas for oxygen before blindly admitting air, otherwise the recognized limit may be considerably exceeded. In exceptional cases the gas itself contains sufficient oxygen without the introduction of a further quantity from the atmosphere. It is interesting to note here the remarks of one authority who, as a result of a great number of experiments, found that an amount of oxygen in excess of 0·3 per cent. was never absorbed from the gas in the purifiers. In view of this, it is contended that as from 0·2 to 0·4 per cent. of oxygen is almost sure to gain admittance during the period for which the retort doors are open, there is no necessity to add a further amount to the purifiers.

When air is admitted at some point prior to the purifiers it must not be overlooked that there is always the possibility of its encouraging undesirable reactions in the wet purification plant. It is, however, an excellent plan to arrange for the air to be introduced on the inlet of the clean water scrubber.

The merits of the " backward rotation " system are chiefly dependent upon the part played by the admitted air. For some time it has been generally understood that the material in a purifier cannot simultaneously extract sulphuretted hydrogen

from the gas and undergo revivification. The assumption is not entirely accurate, as the process of sulphiding invariably takes place at a very much more rapid rate than does the absorption of air. In the case of " backward rotation," therefore, a purifier gradually passes from the position of first " taker," where sulphiding alone occurs, to the end of the series where the oxygen is permitted to carry out revivification undisturbed. In this way each purifier is accorded a period of rest in which to prepare for taking its place once more at the head of the series. Accordingly, with alternate periods of sulphiding and revivification, the boxes may be operated for a lengthened time before requiring remaking, and the material may be worked up to a higher sulphur content. In all it will only be necessary to make from three to four changes before the material is finally spent (containing about 55 per cent. of free sulphur), which contrasts very favourably with the old method, of which Lewis T. Wright wrote in 1895, " Oxide can be economically sulphided and oxidized sixteen times," this meaning that before the material was economically spent it could be thrown in and out of the purifier *sixteen* times.

For most efficient results, so far as revivification *in situ* is concerned, a slight excess of air above the theoretical quantity indicated by the amount of sulphuretted hydrogen present should be employed. Furthermore, the capacity of the plant should be ample, otherwise the air will not produce its due effect.

THE EFFECT OF ADDING AIR

When revivification, owing to admitted air, is taking place in a purifier, a rise in temperature, usually amounting to about 5° Fahr., will be noticed between the inlet and outlet. It is unnecessary to add that no little precaution is necessary in the regulation of the quantity of air used, chiefly owing to its diluent effect as regards the final illuminating and calorific power of the gas, and also with regard to curtailing any abnormal rise in temperature. It is necessary to bear in mind that should any excessive local heating of the oxide take place, instead of a sulphide or a normal sesquisulphide being obtained, a disulphide of iron is formed, or even a sulphate. This is due to too vigorous oxidation. In the case of the disulphide or sulphate of iron, revivification is impossible, and a portion of the material loses its activity in consequence. There is, however, a remedy, for if an alkali is added it will, on account of its basic properties, release the iron from its undesirable combination with the sulphur. The alkali may be added in the form of ammonia from the scrubber, which may be by-passed for a short period; but preferably a small proportion of powdered slaked lime should be admixed to the oxide when it is removed from the box.

So far as the diluent properties of air are concerned, mention may first be made of the oft-quoted work of Audouin and Bérard, carried out in 1862. These investigators found that—

1	per cent.	of	air	reduces	illuminating	power	by	6 per cent.
2	„	„	„	„	„	„	11	„
3	„	„	„	„	„	„	18	„
4	„	„	„	„	„	„	26	„

and if 45 per cent. of air is added the loss of candle-power amounts to 100 per cent.

Later results have been given by Wurtz, who states that—

3 per cent. of air causes 15·69 per cent. loss in light.
5 „ „ „ 24·0 „ „ „

The most recent experiments in this direction have been carried out by Dr. W. B. Davidson. The figures he gives are the following—

1 per cent. of oxygen added decreases candle-power by 3 per cent. and calorific power by 1 per cent.

1 per cent. of nitrogen added decreases candle-power by 2·6 per cent. and calorific power by 1 per cent.

So far as carbon dioxide is concerned, Davidson states that 1 per cent. added to an average sample of coal gas will reduce the illuminating power by 3½ per cent.

REVERSE ACTION

In the ordinary way, the gas enters at the base of the purifiers and passes upwards through the material. Recently, however, it has been pointed out that reverse flow (*i.e.* gas entering above the material and passing downwards) possesses a number of advantages, so that the system is growing in popularity. Foremost, perhaps, is the back-pressure consideration; and when a purifier gives trouble in this direction an effectual remedy will be found in the reverse flow. This is largely on account of the increased area of oxide exposed to the gas, which (owing to the grids) is nearly halved when the flow is in the usual upward direction. When excessive pressure is thrown by a box, it is usually attributable to the first (*i.e.* the bottom) tier, whilst a common remedy is to draw a slide, and so by-pass the one layer. In this respect the downward travel certainly makes matters easier, for the lid may be lifted and the top material lightened (or exchanged for new) with little delay. Thus the efficiency of the box is increased and not reduced materially, as is the case when a layer is slipped.

It occasionally happens that a purifier suffers as regards activity owing to the material becoming too dry. The reverse system in such cases will usually provide a remedy; and if the box is made first "taker," the saturated gas coming away from the scrubbing plant will deposit its moisture on the material and the purifier cover, this in time percolating through the layers, with the desired results. On the other hand, when gas is admitted to the bottom of the vessel, the water is merely deposited in the box, and runs away through the seals. The top tier of oxide in a downward-current purifier is frequently found to be in a muddy condition for a depths of two or three inches when the box is working as first "taker."

A small point worthy of notice is that of revivification. When air is admitted to a box, it is the material at the bottom which (under the common system) derives the greatest benefit from this, and is, consequently, revivified to a somewhat greater extent than the upper tiers. If alternate flow is provided for, however, the uppermost layers are able to derive full benefit from the oxygen present.

Reversal of current is, of course, not to be recommended in the case of oil gas purification.

Purifiers which are fitted for the travel of gas in the usual upward direction may readily be modified so as to cause the gas to take a downward path. Providing that

alternating up and down travel is not desired, the easiest means is that of merely transposing the long outlet pipe, which extends above the grids in the box to the inlet main. Special valves, such as Milbourne's (Fig. 263), can now be had for reversing the direction of flow at will, whilst Dempster's patent device, which is self-explanatory, is shown in Fig. 264.

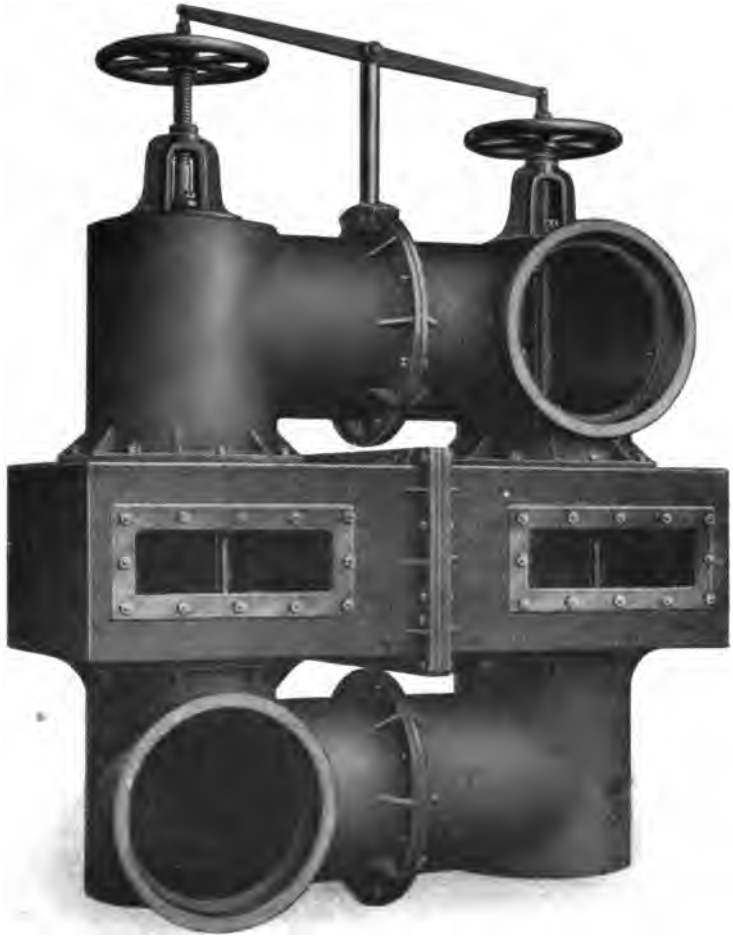


FIG. 263.—MILBOURNE'S VALVE FOR UP OR DOWN FLOW.

At the present day it is common to find a supply of live steam arranged for in the oxide purifiers. Some precaution is necessary in the use of steam in this way, as excessive moisture may give rise to abnormal back-pressure, resulting in the shutting-down of the box. The chief advantage of the steam is the fact that it accounts for some rise in temperature of the gas, whereby the oxide is maintained in a warm condition, which is conducive to its effective working. For this reason it is found that

the efficiency of a purifier may be enhanced by arranging for a steam coil in the gas inlet or in the base of the box—no live steam coming actually in contact with the gas. Raising the temperature of the inlet gas by 10° to 20° Fahr. will frequently be found to get over any difficulty arising from sluggish material. In this respect it will be noticed that when purifiers are partly buried the average temperature of the gas will be somewhat higher than when the vessels are above ground in open sheds or exposed to the weather.

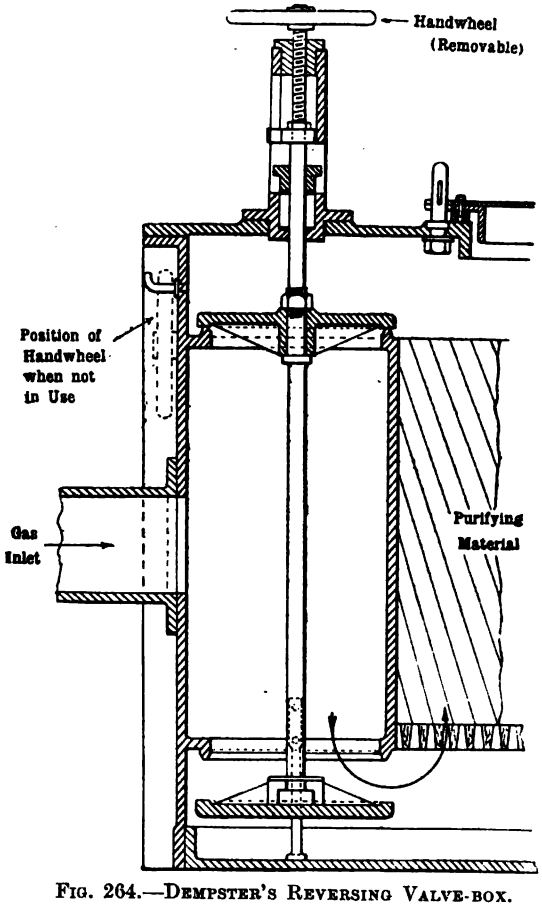


FIG. 264.—DEMPSTER'S REVERSING VALVE-BOX.

When oxide is discharged from a purifier, after the preliminary foulings, it should not be returned to the box before all lumps are broken and the whole reduced to a powdery nature. Thorough pulverization will increase the efficiency of an oxide very considerably. Experiments have shown that whilst one sample of unpowdered oxide after four absorptions contained 37·3 per cent. of sulphur, the same material in the pulverized state contained 47·1 per cent., or an increase in sulphur of 27 per cent. The chief difficulty is that of ensuring that the smaller lumps, about half an inch in diameter, shall be effectively powdered. With hand labour alone the task is most laborious, and the only satisfactory result is obtained with one of the many special disintegrators now to be had.

Oxide may be prevented from caking heavily in the purifiers by adding a small proportion of coarse sawdust on each occasion that the material is changed; whilst it should also be maintained in an alkaline condition. Even though ammonia be allowed to travel forward from the scrubber, the oxide may be found to give an acid reaction; and, whether acid or neutral, enough finely powdered slaked lime should be added to the material to make it alkaline before it is returned to the purifier. The formation of prussian blue, and the general effect of cyanide compounds on the purifying material is fully discussed in the previous chapter (page 369).

MEETING EMERGENCIES

Whatever care may be bestowed upon the purification plant, it is occasionally the experience of every engineer to find that a perceptible trace of sulphuretted hydrogen is getting through into the finished gas. When such is the case, quick action is usually necessary, and the following three remedies are suggested—

(1) If a small proportion of air is injected into the gas at the *outlet* of the purifiers, the trace will very frequently be temporarily cleared.

(2) If the material in the purifiers is obviously at fault, the top tier of the final box may be rendered extremely active by being covered with a 2-inch layer composed of fresh oxide and hydrated oxide (*i.e.* chemically prepared material). The last named is prepared by mixing together about 1 ton of ground copperas with an equal amount of lime, care being taken to ensure that the lime is present in sufficient quantity to make the mixture alkaline.

(3) The trace of sulphuretted hydrogen may be due to chemical action in the gasholder. The cause of and remedy for such derangements are discussed in the next chapter.

LIME PURIFICATION

Lime in the hydrated or slaked condition is an active absorbent for sulphuretted hydrogen and carbon dioxide, and—under certain conditions—is capable of removing a proportion of the remaining sulphur compounds. On the smallest of works, where the amount of sulphur recoverable would (owing to cost of carriage and other considerations) not materially affect the receipts, lime is used exclusively. On the larger works its use has been largely discontinued, owing to there no longer being any statutory objection to the small quantity of sulphur compounds—other than sulphuretted hydrogen—travelling forward to the district. The admixture with coal gas of water gas, which contains but a small proportion of sulphur compounds, has tended to curtail considerably the total quantity of these compounds in the mixed gases. In the case of those concerns where coal gas alone is manufactured, the removal of a portion of the carbon disulphide is still usual. In some instances it is effected by methods known as " hot " purification, but more generally with the aid of lime.

The sulphur compounds remaining in the gas after the sulphuretted hydrogen has been removed consist almost wholly of carbon disulphide (which is present to the extent of about 0·02 per cent.). Of the remainder, thiophene is the chief constituent, but so far the other compounds have not been distinguished.

In studying purification by lime it is, primarily, necessary to bear in mind that of the three acid gases involved, carbon dioxide has the strongest acidic properties, sulphuretted hydrogen following next, with carbon disulphide last in order. Thus when the crude gas meets an active base such as slaked lime there is a tendency for the most vigorous acid to be absorbed first. The combination between lime and CO_2 takes place on simple lines, as follows—

$$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O.$$

Sulphuretted hydrogen reacts with lime in the following manner—

$$Ca(OH)_2 + SH_2 = CaS + 2H_2O.$$

Thus, as before explained, the whole of the purification can, by employing a sufficiency of material, be carried out with lime. The great drawback to such methods, however, is the loss of the sulphur, which cannot be recovered in useful form, as is the case where oxide of iron is employed. As explained above, when the gas from the wet purification plant enters the first (lime) purifier, the CO_2 is absorbed to the greatest extent, although some sulphuretted hydrogen is also removed. As the process proceeds, this sulphuretted hydrogen is displaced by the stronger acidic nature of the CO_2, and the spent material consists almost wholly of the carbonate. The manner in which the sulphide is displaced is shown as follows:—

$$CaS + CO_2 + H_2O = CaCO_3 + SH_2.$$

If a small proportion of air is admitted to the purifier, a certain amount of the calcium sulphide will be converted into free sulphur, and will thus escape ultimate decomposition by CO_2.

In preparing ordinary dry lime for use in purifiers, the material should be well slaked with water, and as much as possible of the "core" (*i.e.* inert matter, such as chalk, stones, etc.) should be removed by screening. In addition to the water actually required for slaking, the lime should contain a further 30 per cent. of moisture. Excessive watering will, however, give rise to caking. Caking, and consequent loss in power of absorption, may also result from too much sulphuretted hydrogen having been passed through the lime, this occasionally occurring in those boxes which are set aside for the removal of CS_2. So far as the thickness of the layers of lime is concerned, it may be pointed out that a depth of about 8 inches is preferable to the thinner layers of 4 and 5 inches which were often employed in the past. Whatever the type of purifying material, a thin layer is likely to "blow" and thus permit a certain amount of gas to escape untreated.

When gas manufactured at the larger works is to be freed from the whole of its impurities, it is usual to instal a system in which oxide of iron and lime are used in conjunction. In this way the greater proportion of the sulphuretted hydrogen may be recovered and not wasted. Many methods of operating the purifiers for this purpose have been employed, but the whole principle may be readily grasped by a consideration of the well-known Beckton system. It consists in the main of four sets of purifiers operated in rotation—

First set.	Contains lime.	These remove the whole of the CO_2 and some SH_2, which is afterwards displaced by CO_2. Some CS_2 is also absorbed.
Second set.	Contains oxide of iron.	These remove the whole of the SH_2, including any which may be displaced from the lime in the previous set.
Third set.	Contains lime.	This lime has been previously "sulphided" and removes the bulk of the CS_2. It will not remove the *whole* of this impurity.
Fourth set.	Contains oxide of iron.	These vessels act as "catch-boxes" and remove any SH_2 which is disengaged from the third set.

In order to understand the method of working, it must be borne in mind that ordinary slaked lime—*per se*—has no action upon carbon disulphide. The chemical

reactions involved in the elimination of this impurity are somewhat complex and are set out below. First, it will be seen that the calcium hydrate must be "sulphided" by passing through it a stream of sulphuretted hydrogen. For this purpose the crude gas, after travelling through the first set of purifiers, is led direct into the third set, the oxide vessels comprising the second series being by-passed for the time. Working in this way is continued until sulphuretted hydrogen is noticed at the outlet of the lime boxes forming the third set. At this juncture the two oxide vessels (second set) are put into action. The lime vessels forming the third set are then in a condition to absorb carbon disulphide, and purification proceeds as outlined above. Of the total CS_2 present, up to 20 per cent. may be removed by the first lime vessels, 55 per cent. by the sulphided boxes, whilst about 25 per cent. will remain in the gas.

The total amount of sulphur compounds (other than SH_2) in crude coal gas varies in normal cases from 35 to 50 grains per 100 cubic feet, although in exceptional instances the figure may rise to 60 grains.

CHEMICAL REACTIONS IN CS_2 REMOVAL

The exact nature of the chemical reactions occurring during the removal of carbon disulphide is still open to question. It should be stated at once, however, that although the active medium consists primarily of calcium sulphide, and although this compound in the moist state is capable of absorbing CS_2, the reaction is certainly *not* represented by the following simple equation—

$$CaS + CS_2 = CaCS_3.$$

The most enlightening work on the subject has been carried out by Veley (1885), whose theory is generally accepted as correct. This investigator concluded that the compound which absorbs the CS_2 is not calcium hydrosulphide (as has sometimes been supposed), but calcium hydroxyhydrosulphide (CaS,H_2O, or CaOH.SH). The hydroxyhydrosulphide, it is understood, is formed in the following manner—

(1) Calcium hydrosulphide results in the first place—

$$Ca(OH)_2 + 2H_2S = Ca(SH)_2 + 2H_2O.$$

This compound $Ca(SH)_2$ has no action on the CS_2.

(2) By the addition of water or oxygen the hydrosulphide is then converted into the hydroxyhydrosulphide—

(*a*) $Ca(SH)_2 + H_2O = CaOH,SH + SH_2$

or

(*b*) $2Ca(SH)_2 + O_2 = 2CaOH,SH + 2S.$

The former reaction is the one most likely to occur in practice, for oxygen will seldom be present at this stage.

(3) The CS_2 and calcium hydroxyhydrosulphide interact as follows—

(*a*) $2CaOH,SH + CS_2 = SH_2 + Ca(OH)_2,CaCS_3$

or

(*b*) $3CaOH,SH + CS_2 + H_2O = 2SH_2 + 2Ca(OH)_2,CaCS_3.$

In either case it will be seen that sulphuretted hydrogen is thrown off and is absorbed in the final oxide boxes.

Derangements with lime purification are only too common, owing to the difficulty of applying in practice a series of somewhat delicate chemical operations. Occasionally the sulphided boxes will actually throw off carbon disulphide, and thus increase instead of reduce the sulphur compounds in the gas. If adequate precautions are taken, however, this trouble should not occur. The chief necessity is that of ensuring that no CO_2 should be allowed to travel forward to the CS_2 boxes. The CO_2 will instantly displace the carbon disulphide, which must then travel forward with the gas. An important point to bear in mind is that the sulphiding action should never be carried out at a low temperature, otherwise the activity of the material may be impaired. The temperature of the lime during this operation should, if possible, be maintained at about 50° Fahr., although this will not always be possible during winter. An inactive purifier may frequently be revivified by the injection of a small quantity of air, the oxygen probably reacting with the hydrosulphide and oxidizing it to hydroxyhydrosulphide, as shown in the above equation.

THE CONSTRUCTION OF PURIFIERS

Purifiers, as used in gasworks, are generally constructed of cast iron (ferro-concrete has lately been experimented with), and may be classified into three distinct groups—

(*a*) Water-lute vessels, the type originally employed and still largely made use of, the lute varying from 15 inches to 40 inches deep.

(*b*) Dry-lute purifiers, a modification of the above, in which the use of a hydraulic joint is dispensed with.

(*c*) Purifiers, such as Green's well-known type, in which small sections of the cover are alone removable. These are fitted with dry joints.

All the above groups may again be erected—

(*a*) At ground level, or partially buried.

(*b*) Above ground level, *i.e.* overhead types.

So far as the arrangement of the purification plant is concerned, irrespective of the design of the actual vessels, it is essential to provide facilities for rapid and economical discharging and charging. It will be seen at once that where ground space is a consideration the overhead system should be decided upon, as in this way a floor space for mixing and revivification is provided beneath the vessels. With the ground-level system a special preparing floor must be arranged for alongside the boxes. When ground-level or sunk purifiers are employed they usually rest on a plain, flat slab of concrete. The nature of the subsoil should, however, be carefully ascertained, as piling or other methods may be necessary (*see* page 31). Overhead types are supported, usually from 10 to 12 feet above the lower floor, on cast-iron columns or steel stanchions braced together by cross girders, which provide a seating for the boxes.

In large works the purification plant is comparatively costly, but some outlay may be saved by arranging the vessels so that they butt one on to another, with one

division plate, thus saving a side plate between each pair. This arrangement applies to dry-lute purifiers alone.

With overhead purifiers the gas outlets are often constructed in such a manner as to form a discharging shoot to the floor below; in this way the spent material may be easily shot to the lower level and spread out in layers to undergo revivification. After revivification the material is carried up to the upper floor, in the smaller works by manual labour, and in larger works by some form of lift, elevator, or crane. With overhead purifiers the operation of discharging and recharging may be carried out in a half or a third of the time required with ground-level systems, where a considerable amount of wheeling to and fro has to be done. Other advantages of the overhead types are that they are very much more accessible for painting and repairs, whilst there is less capital outlay on land. The outstanding merit of the ground-level purifiers is their comparatively moderate cost, whilst maintenance charges are lower, owing to the absence of heavy girder-work and stanchions. In cases of treacherous subsoils it may not be possible to adopt the overhead type, owing to the impossibility of concentrating the whole load on small areas (*i.e.* the bases of the standards). In spite of their good features, the overhead purifiers are comparatively rare. The explanation probably lies in the fact that the interest accruing from the additional capital expenditure involved, combined with increased maintenance costs, would probably be a greater item than the saving which would be effected in labour.

THE SIZE OF PURIFIERS

It is essential that purifiers should be of ample capacity for the work they are called upon to perform. Nothing is more detrimental to working efficiency than an overloaded series of purifiers, and the cost of an additional unit can soon be expended in labour charges owing to the shorter life of the material when capacity is inadequate.

For oxide purification alone it will suffice if the following allowance is adhered to—

Set of four purifiers: Allow, as a minimum, an area of 0·5 square foot per 1,000 cubic feet of gas to be purified per day. This is the allowance for *each* box, and not the total area of all boxes. If lime is to be used for the removal of sulphur compounds, the figure should be increased to 0·6 square foot, or 0·65 to 0·7 square foot if no "catch-boxes" are available.

So far as the *total* area of all boxes is concerned, Hunt states that for lime and oxide purification combined 20 to 30 square feet per ton of coal carbonized per day should be allowed.

As has already been pointed out in Chapter I, it is essential to make provision for future requirements, and so far as a new works is concerned it is preferable to erect only three boxes to each unit, provision being made for the easy addition of the fourth when it is required. In such cases the three boxes should be constructed with a capacity 50 to 60 per cent. larger than that necessary in a group of four; that is, an allowance for each box of 0·8 to 0·85 square foot per 1,000 cubic feet of gas passing per day. Considering the case of a very small works with prospects, it

would be advantageous to provide only two boxes at the outset. Each box, however, should be of large capacity, say 1·5 to 1·7 square feet per 1,000 cubic feet per day. In this way there will be very little increase in first cost (as compared with a system of three small purifiers), and money will be saved when extensions are carried out.

Within certain high and low limits purifiers may be constructed of almost any dimensions. They are invariably square or rectangular in shape. The minimum size is usually 4 feet square by 3 feet in depth, whilst the maximum size will not, except in abnormal cases, exceed 1,600 superficial feet, *i.e.* boxes having sides of 40 feet. A vessel of this description would be capable of dealing with about $2\frac{3}{4}$ million cubic feet per diem; consequently, in the case of those works making more than this quantity of gas, it is necessary to split the stream prior to reaching the purifiers and to treat it in two (or a number of) separate units.

The body of a purifier is invariably constructed from cast-iron plates, bolted together, the joints being made in the usual manner from borings, or faced and red-leaded (*see* page 348). On the other hand, it is essential that the lid of the vessel should be light, to which end it is built up from steel or wrought-iron plates (usually $\frac{1}{4}$ inch thick) and suitably braced with rolled steel sections. Owing to the necessity of maintaining a clear passage for the cover in the water-lute, the flanges of purifier plates are frequently arranged in a somewhat unconventional manner. The construction of the lute, showing the way in which the flange changes over from the exterior to the interior, and the method of bolting on the separate lute plate and the base plate, will be followed from Fig. 265. It should be noted that in the case of a ground-level vessel the flanges would be internal, and not external. In this way the joints and bolts, being inaccessible from below, can be attended to from the interior. So far as the thickness of the cast-iron plates employed is concerned, the following figures may be taken as satisfying all requirements—

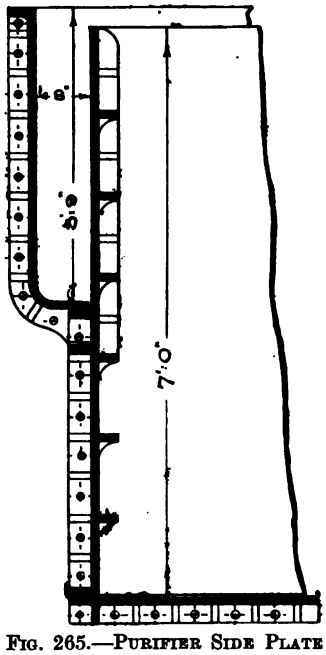


FIG. 265.—PURIFIER SIDE PLATE (CAST-IRON).

Purifiers up to 10 feet square . .	$\frac{5}{8}$ inch plates.
" " 20 " " . .	$\frac{11}{16}$ " "
" above 20 " " . .	$\frac{3}{4}$ " "

Flanges are cast $\frac{1}{16}$ inch or $\frac{1}{8}$ inch thicker.

The common methods of jointing cast-iron plates together are described and illustrated on page 348. Side-plates are usually cast with a width of four or five feet for standardization.

The smallest purifiers are usually three feet deep, and the largest sizes vary from six to eight feet deep. Intermediate sizes are four to six feet in depth. As a rule

for ascertaining the required depth for a purifier, the author suggests the following—

$$\text{Depth in feet} = \sqrt[4]{\text{Total superficial area} \times 1{\cdot}1}$$

The depth may then be taken to the nearest foot—portions of a foot being neglected owing to the general practice of casting these plates in lengths divisible by a foot. For smaller purifiers, that is boxes with an area up to 300 square feet, multiply by 1·3 instead of 1·1.

Thus, considering a purifier 30 feet × 30 feet

$$\text{Total area} = 900 \text{ square feet}$$

$$\sqrt[4]{900} = 5{\cdot}47 \text{ and } 5{\cdot}47 \times 1{\cdot}1 = 6{\cdot}017 \text{ feet.}$$

Therefore the required depth is six feet.

Again, with a smaller purifier, say 12 feet × 16 feet

$$\text{Total area} = 192 \text{ square feet.}$$

$$\sqrt[4]{192} = 3{\cdot}725 \text{ and } 3{\cdot}725 \times 1{\cdot}3 = 4{\cdot}84 \text{ feet.}$$

Accordingly required depth is 5 feet.

PURIFIER CONNECTIONS

The size of the gas main working in connection with purifiers may be best calculated as follows—

Diameter of pipe in inches $= \sqrt{\text{area of each box in square feet.}}$ For small purifiers (up to 60 square feet area) the result can be taken as it stands, but for medium size boxes deduct one-sixth and for large boxes one-fourth. As an example, consider a square purifier with 40 feet sides, then—

$$\begin{aligned}\text{Diameter of pipe in inches} &= \sqrt{1{,}600} \text{ less one-fourth} \\ &= 40 - (\tfrac{1}{4} \text{ of } 40) \\ &= 40 - 10 = 30 \text{ inches.}\end{aligned}$$

i.e. a 30-inch main would be used.

Another rule which may be conveniently employed is that due to Milbourne—

Diameter of pipe in inches =

$$\frac{\text{Length and breadth of purifier (in feet)}}{2} \times 0{\cdot}7$$

thus, with a 40-feet square purifier we get—

$$\frac{40 + 40}{2} \times 0{\cdot}7 = \frac{80}{2} \times 0{\cdot}7 = 28 \text{ inches.}$$

In such a case it would be decided to put in the next largest standard size of main, *i.e.* a 30-inch pipe.

GENERAL CONSTRUCTIONAL NOTES

Ordinary water-lute purifiers are constructed from side plates having the lute made as portion of the plate itself, or with the lute as a distinct casting (Fig. 265). From the economical standpoint the former type is preferable, first, owing to the initial outlay being less, and secondly, on account of the greater ease with which it is erected. With both types the most costly section is the corner plate. The depth of the water lute (usually half the depth of the box) is an important consideration, and it must be ensured that the depth of water obtainable will be sufficient to withstand the heaviest pressure which is likely to prevail inside the vessel. Covers for

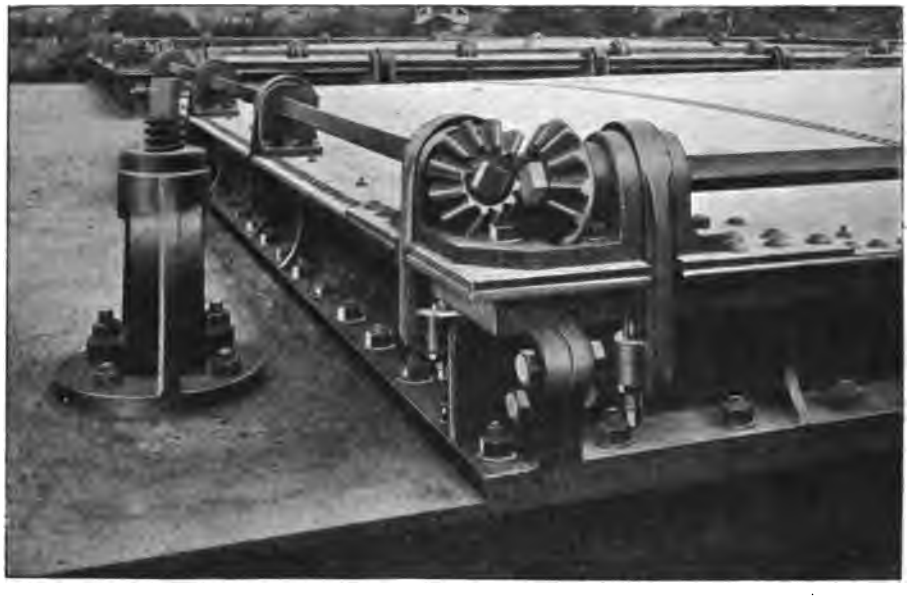


FIG. 266.—MILBOURNE'S COVER FASTENER.

purifiers may be either flat or curved. In either case some form of trussing or stiffening will be required, and strong curbs should be provided when the vessel is of any size. So far as lifting is concerned, the cover, when of the domed type, is usually provided with a stout lifting-eye attached to straps, which are in turn riveted to the side plates and again to the bottom curb. With the flat cover, which is invariably employed with dry lutes, the lifting is frequently carried out by means of eyes attached to the external stiffening sections or trussing. The floor plates of purifiers should, when possible, have internal flanges, thus avoiding local stress on the bottom plates. The box, moreover, when of the ground-level type, obtains a level bearing on the concrete and the joints are readily accessible. The plates of purifiers should be designed with as few different patterns as possible, whilst an eye must be given to the avoidance of awkward castings. When the plates are large, they must be adequately stiffened. Some means should always be provided for by-passing the

separate tiers of material should this be necessary owing to abnormal back-pressure. Special tier-valves are made for the purpose, although a mild-steel plate

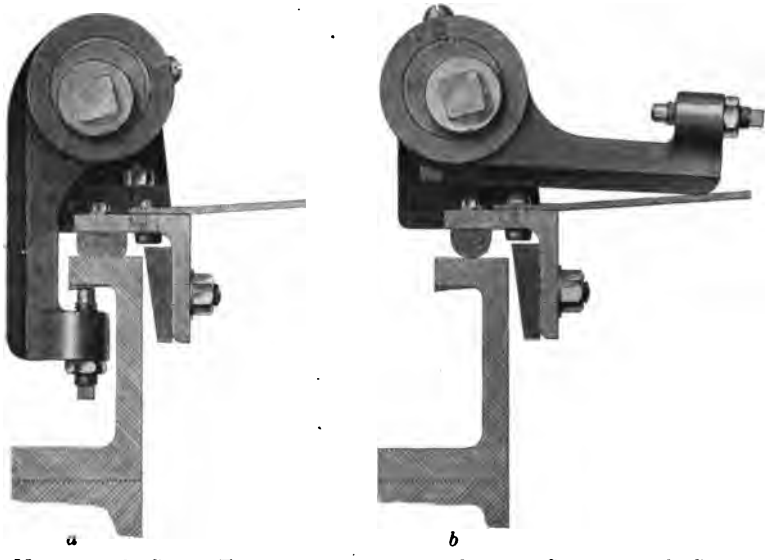


FIG. 267.—MILBOURNE'S COVER FASTENER, SHOWING (*a*) CATCHES SHUT, AND (*b*) CATCHES OPEN.

attached to a rod passing through a stuffing-box on the purifier will answer the purpose equally well. This plate lies flat on the grid, and is not covered with the

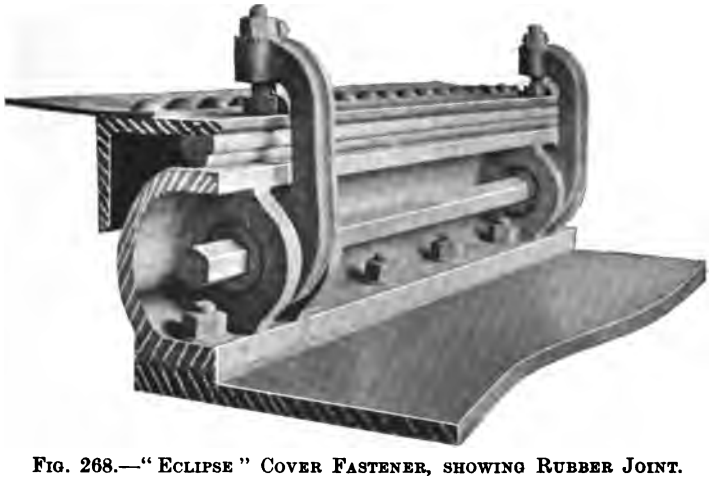


FIG. 268.—"ECLIPSE" COVER FASTENER, SHOWING RUBBER JOINT.

purifying material. In addition, it is a good plan to have a pressure cock fitted to each layer.

The chief advantages of the dry-lute purifiers may be summarized as follows—

(*a*) Lower initial cost.

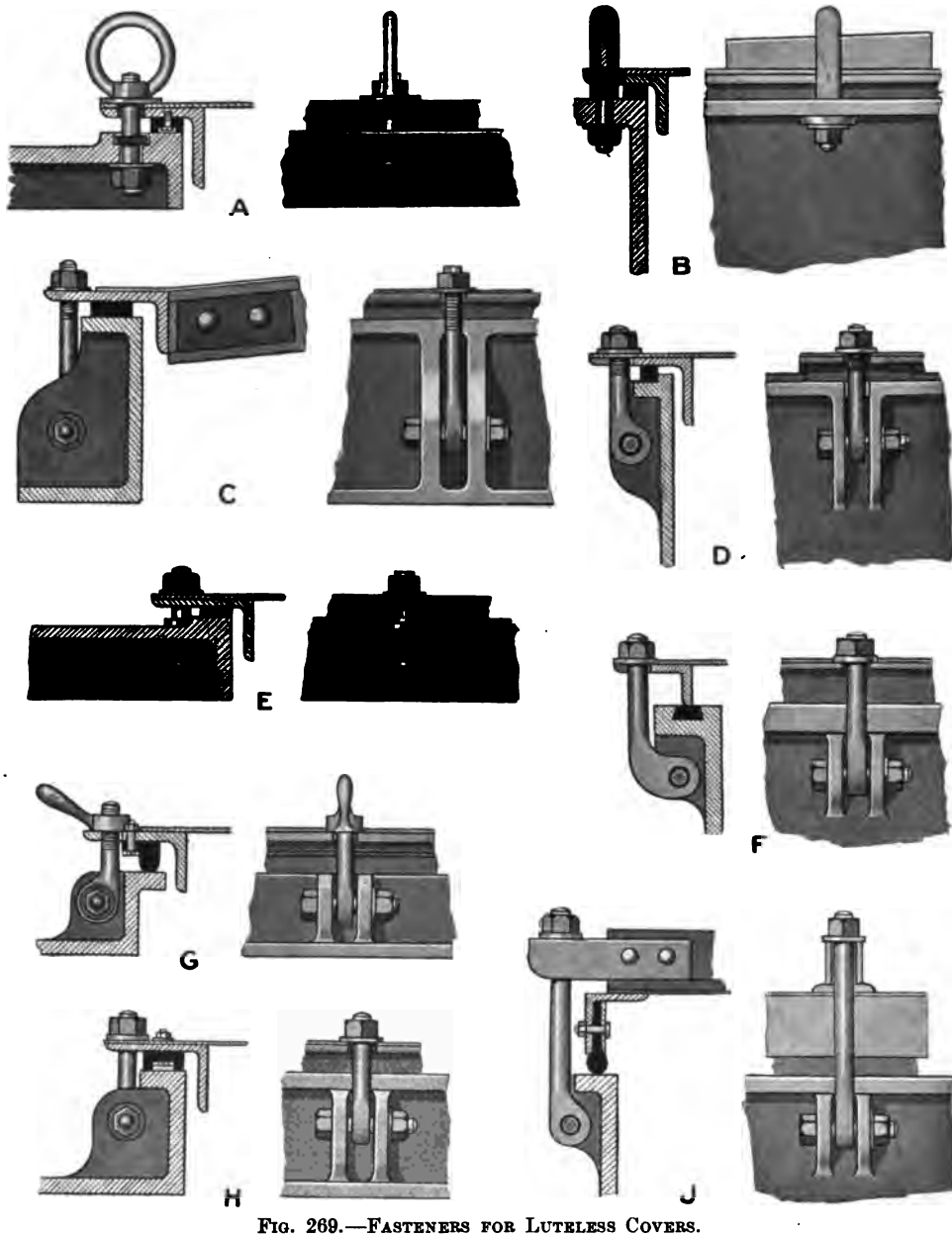


FIG. 269.—FASTENERS FOR LUTELESS COVERS.

(*b*) Increased safety, owing to the elimination of the water seal, which is liable to evaporate, thus lessening the seal.

(*c*) They will not " blow " in the event of a temporary excess of back-pressure.

(*d*) Greater durability.

(*e*) There is no risk of frozen lutes in winter, with the consequent absence of anxiety.

(*f*) Owing to the lighter construction of the lids, the lifting apparatus is not so cumbersome.

There are several types of jointing material made use of with luteless purifiers. A gas-tight joint is ensured by a strip of rubber or tallowed hemp inserted between the flanges of the cover and side plates. The two flanges are then pulled together by ordinary bolts and nuts inserted at a pitch of about twelve inches. The most effective arrangement, however, is an automatic catch attached to a shaft running throughout the length of the side of the box. By means of an eccentric movement the holding-down catches can then be released simultaneously along the whole side.

FIG. 270.—MILBOURNE'S JOINTING FOR DRY LUTES.

Milbourne's fastener is illustrated in Figs. 266 and 267. In this case the complete cover is released from one point, about thirty seconds being required for the operation. Special fastener clutches, spaced at intervals of about three feet, are actuated by eccentric discs attached to square steel rods running along the edge of the cover and connected at the corners by bevel gearing. When a cover is unfastened the first portion of the stroke of the operating lever imparts a downward vertical motion to the fastener clutch, whilst the second portion of the stroke swings the clutches out of position. When a lid is tightened up the reverse occurs. The " Eclipse " fastener is shown in Fig. 268. In this case the fastener is fixed to the side of the purifier, the steel shaft running beneath a raised cast-iron flange. When the cover is released the whole of the catches fall clear, and leave the cover a free passage for lifting. So far as the various means of jointing are concerned, the main difference lies in the formation of the rubber strip and as to whether it is applied to the upper or lower curb. Common types are shown in Figs. 268, 269, and 270.

LIFTING GEAR

In small works the cover may be lifted by means of eyebolts or hooks attached to it, with pulley blocks running on a horizontal joist overhead and supported at each end by columns of timber, cast-iron or steel. In medium-sized and large works, a common lifting-gear is that composed of two " A " frames running on rails on either side of the purifiers. The apexes of the two " A " frames are then connected by a single joist or a lattice girder. Travelling can be effected by hand, a purchase being obtained by means of suitable toothed gearing. The actual lifting of the cover may be carried out by pulley blocks, or in the case of very heavy covers by means of hydraulic or other power. Where electric power is available an overhead crane of the shop or foundry pattern can be used with advantage.

THE PRESSURE ON PURIFIER COVERS

It should be borne in mind that in the case of purifiers with a water-luted cover, the internal gas pressure on the box and cover is limited by the depth of water in the seal. The pressure which the cover has to withstand, therefore, is the total pressure of the gas on its (the cover's) area, less the weight of the cover itself. Holding-down lugs have, therefore, to be constructed accordingly. The bracing of the cover must also be strong enough to avoid distortion of the members, with its consequent tendency towards leaking rivets. When abnormal pressure occurs the lute in this type of purifier forms the safety valve, and the seal " blows."

In dry-luted covers the pressure provided for must be greater, and a normal specified test would be 1½ lb. per square inch, *i.e.* a water column of 3 feet 6 inches. As the holding-down bolts are closer together than in the water-lute purifier, no difficulty is found in designing them of sufficient area to withstand the upward tension. When domed tops are employed the pressure is less than with the flat top, and an allowance for this can accordingly be made.

PURIFIER GRIDS

The most usual form of grid employed for supporting the material within the

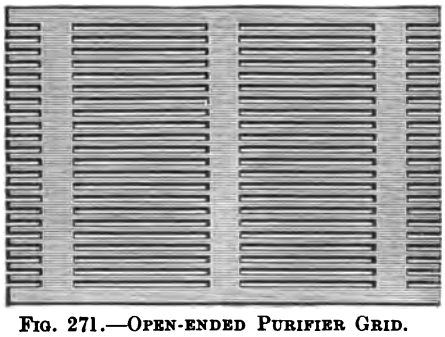


FIG. 271.—OPEN-ENDED PURIFIER GRID.

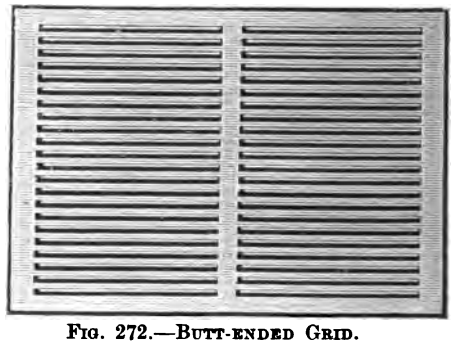


FIG. 272.—BUTT-ENDED GRID.

purifier is the flat sieve, made in wood, and built up with either open or butt-ends, as shown in Figs. 271 and 272. Within recent years there has been some tendency

to employ grids of the hurdle type, either by themselves or in conjunction with the ordinary flat sieves. The chief advantage attached to such grids is that they may, in some cases, be responsible for a reduction in back-pressure, but it seems that their advantages are almost entirely outweighed by their defects. Amongst the latter may be mentioned—

(*a*) The tendency of the gas to short-circuit through the material.

(*b*) The wear and tear on the grids is greater.

(*c*) A common method of overcoming back-pressure in an ordinary purifier is by drawing a slide and thus by-passing a tier of the material. With the hurdle grid this cannot be done.

(*d*) The operation of discharging is more costly, and occupies a greater length of time.

It must not be supposed, however, that the hurdle grids have not their good points, and many engineers adhere entirely to their use. For the plain flat sieve the average cost is about 6*d*. per square foot, in normal times.

THE COST OF PURIFIERS

No definite figure for costs based on the capacity per 1,000 cubic feet of gas dealt with can be given, owing to the expenditure per unit volume undergoing considerable reduction as the capacity increases. For instance, a set of four purifiers complete with connections, lifting crane, etc., to deal with 100,000 cubic feet of gas per diem, will cost about £500, *i.e.* £5 per 1,000 cubic feet; whilst a similar set capable of taking two million cubic feet per diem will run into rather more than £4,500, *i.e.* £2 5*s*. per 1,000 cubic feet. These figures refer to dry-luted, ground-level boxes, and do not include the building. If water-luted boxes are under consideration, 15 to 20 per cent. may be added. The diagram shown in Fig. 273 gives an indication of the manner in which the cost varies in accordance with the capacity. The figures include connections, lifting gear, valves and foundations. The following table shows the manner in which the outlay is distributed over the various portions of the installation in normal cases for medium-sized plant—

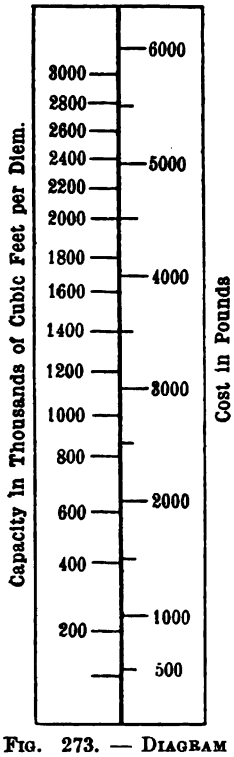


FIG. 273. — DIAGRAM SHOWING APPROXIMATE COST OF A SET OF FOUR PURIFIERS.

Purifying boxes	. .	50 per cent. of total expenditure.
Covers (dry lute)	. .	15 „ „ „ „
Lifting apparatus	. .	4 to 6 „ „ „ „
Grids (ordinary flat type)		6 to 10 „ „ „ „
Connections and valves	.	20 to 30 „ „ „ „

Castings for the boxes, etc., cost, normally, from £10 to £11 per ton. The covers cost from £17 to £19 per ton, or the whole set, including connections, from £12 to £13 per ton.

So far as the cost of buildings is concerned, this has already been touched upon in Chapter I. If a steel-framed, brick-panelled structure is erected the cost will amount approximately to $2\frac{3}{4}d.$ per cubic foot capacity, including foundations. This type of building is, however, rarely employed, and the modern tendency is to erect a light steel-framed shed carrying a roof, but open at the sides. Such a building may be estimated at 1*s.* 6*d.* per square foot of area covered.

PURIFIER VALVES

The valves made use of on purifiers are commonly of three distinct types—

(*a*) Centre valves.

(*b*) Separate slide valves (such as the well-known rack and pinion type).

(*c*) Hydraulic valves.

One type of centre valve is shown in Fig. 274. This valve is constructed with

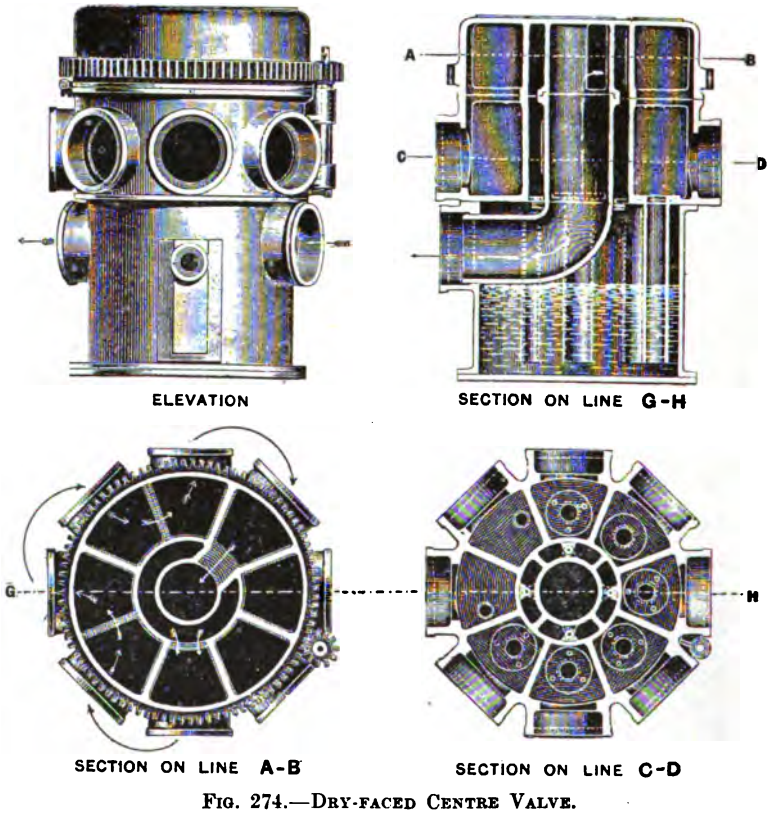


FIG. 274.—DRY-FACED CENTRE VALVE.

dry faces, and enables any number of the four purifiers to be in action at one time. It is claimed that with valves of this description, as the faces are always covered when at work, no deposit of any kind can collect, thus leakage from one valve chamber to another is precluded. Hydraulic centre valves, in which water is the sealing medium, are also employed, but the ordinary type possseses the disadvantage that

it will only operate the purifiers in one combination, *i.e.* any three boxes at work with one out of action. The construction of the centre valve is somewhat complex, but an idea of the principle may be obtained from the diagrammatic representation given in Fig. 275.

Walker's type of rack and pinion valve is shown in Fig. 276, whilst the ordinary single water valve is seen in Fig. 277. These water or hydraulic valves are of simple construction and consist of a rectangular cast-iron box with a mid-feather extending to within a short distance of the bottom. When water is admitted to the box the gas way is stopped, and in order to open the gas passage the water is merely run off from the drain pipe at the base. The depth of seal employed in these valves is usually the same as that in the seal of the purifier cover.

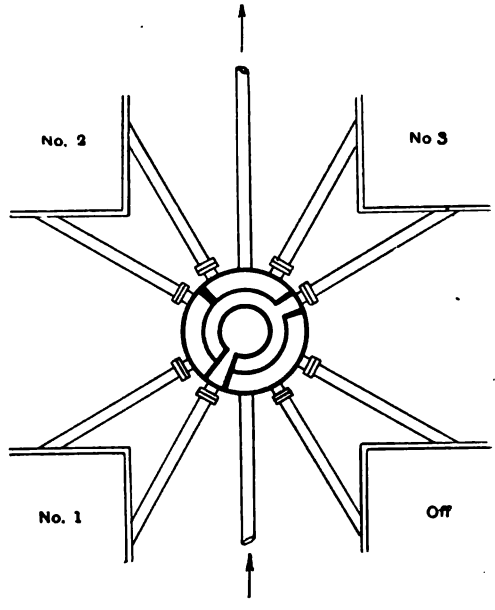


FIG. 275.—DIAGRAM SHOWING PRINCIPLE OF OPERATION OF CENTRE VALVE.

FIG. 276.—RACK AND PINION VALVE. WALKER'S TYPE.

So far as the relative advantages of the various types of valves are concerned, the following points may be stated—

(*a*) Centre valves. Are simple in operation, but may give trouble owing to gas leaking from one valve chamber to another. If this occurs a portion of the crude gas may get through to the clean gas outlet and give rise to a stain.

(*b*) Slide valves. These may be either of the rack and pinion or worm and rack type. They should be flanged so that they may be readily replaced if faulty. One spare valve should always

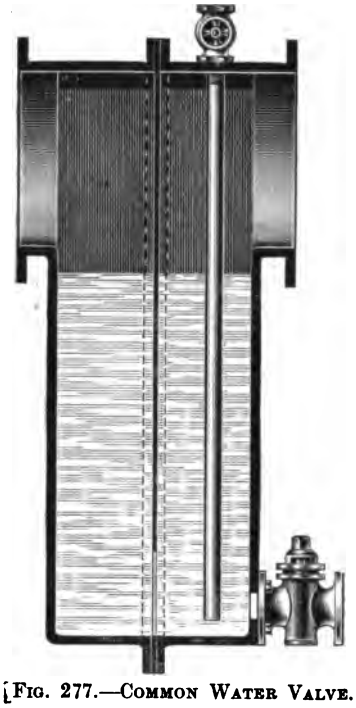


FIG. 277.—COMMON WATER VALVE.

be kept as a stand-by. If this is done all the valves in use can be overhauled in turn.

(*c*) Water valves. These valves are probably the safest, but they are undoubtedly cumbersome, and decidedly slow in action in comparison with the other types. The latter disadvantage is, however, not of paramount importance at the present day, owing to the extended life of each purifying vessel.

A novel device in the construction of purifier valves is the "Bearscot" patent operating gear (Fig. 278), which has for its object the revolving and grinding in of various kinds of valve discs upon their seatings. When, as often happens, valves remain either closed or open for long periods, tar, sediment, and other undesirable substances are apt to accumulate on the exposed face, thus preventing close contact between the disc and its seat. The method under notice makes the grinding in of the disc a very simple matter. When closing a valve, when the disc is coming in contact with the face of the valve, the small lever marked "A" is swung, so that the tooth gears into one of the recesses on the hand-wheel marked "B." This action locks the spindle and disc to the handwheel. The operator then moves the handwheel to and fro, thus revolving the disc. The lever is then raised, releasing the spindle, and the handwheel is turned slightly, thus tightening the disc on the seat. The lever "A" is again geared with the handwheel, and the disc further revolved. When the disc is fairly bedded down, the lever is raised, and the valve closed home, thereby ensuring that the faces are in complete contact and the valve absolutely gas-tight.

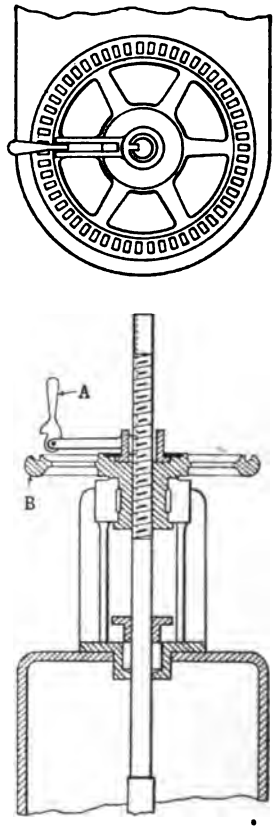


FIG. 278.—"BEARSCOT" VALVE OPERATING GEAR.

THE COST OF PURIFIER VALVES

All forms of purifier valves are somewhat costly, this applying in particular to the centre types. The most general method of arriving at an approximate price for valves is to allow so many pounds (money) per inch diameter of the valve. The following may be taken as normal figures—

Ordinary rack and pinion valve	£1	per inch diameter.
Centre valves	£9	,, ,,
Weck's centre valve and such types	£10 10*s.*	,, ,,

PURIFYING CAPACITY OF MATERIAL

One ton of good quality (Dutch) bog-ore may be considered capable of removing the sulphuretted hydrogen from two to two and a half million cubic feet of gas before it is finally spent. The quantity of lime required to extract carbon dioxide varies in accordance with the amount of inert matter or "core" present in the lime. In the usual way, from 3½ to 4 yards are necessary per million cubic feet of gas. In the case of lime purification methods for complete removal of all impurities from the gas (*i.e.* when lime is used in conjunction with oxide), the quantity of lime may amount to 5½ cubic yards per million cubic feet of gas.

THE REDUCTION OF SULPHUR COMPOUNDS

It has already been pointed out that the sulphur compounds remaining in coal gas after the extraction of sulphuretted hydrogen consist for the most part of carbon disulphide, which is present to the extent of about 0·02 per cent. by volume, or from 25 to 50 grains per 100 cubic feet of gas. The carbon disulphide represents about 75 to 80 per cent. of the impurities classed as "sulphur compounds," the constitution of the remaining 7 to 10 grains being still uncertain. No doubt, from 60 to 70 per cent. consists of thiophen, whilst it seems probable that the remainder is partly accounted for by ethyl and methyl sulphides and certain mercaptans.

Processes by means of which carbon disulphide may be partly, or in some cases wholly, removed may be summarized as follows—

(1) Purification by means of sulphided lime (*see* page 397).

(2) The decomposition of CS_2 by heating, as in the Oregon process.

(3) The decomposition of CS_2 by heating in the presence of a catalyst, such as in the Carpenter-Evans process.

(4) The interaction of CS_2 with certain amino compounds such as aniline.

(5) The liming of coal in the retorts.

(6) The absorption of CS_2 by means of alkalinated cellulose, as in the "Athion" process.

If CS_2 is heated to a suitable temperature, in the presence of hydrogen, the following reaction will occur—

$$CS_2 + 2H_2 = 2H_2S + C.$$

This reaction is the basis of the modern systems of "hot" purification, but owing to the extremely small quantities in which CS_2 is present in coal gas it is essential that the reaction, if it is to be effective, should be of extremely high velocity.

The inception of purification methods on these lines is due to the inventors of the Oregon process, who, after numerous experiments with apparatus which proved unsuitable, evolved apparatus very similar in appearance to the carburettor of a modern water-gas plant. These investigators found that when the gas was passed through a vessel containing broken firebricks at a temperature of about 1,600° Fahr., the CS_2 was decomposed into sulphuretted hydrogen and free carbon. The plant employed consisted of two cylindrical vessels lined with fireclay and packed with firebricks laid chequerwise. The vessels were heated internally by the combustion of producer gas, and whilst one was being heated, the second was purifying the gas, and *vice versa*. That is to say, when the vessel which was purifying was cooled down by the inflowing gas to a temperature at which its efficiency was low, the operations were reversed, the gas being diverted to the second vessel, which had been undergoing a spell of reheating. In a series of experiments, extending throughout 1909, it was found that the average reduction in the quantity of sulphur compounds amounted to 71 per cent. In a process of this description, where no catalyst is employed, temperature must necessarily play an important part. The inventors found that at 800° Fahr. the percentage reduction averaged only 20·7 per cent., whereas at 1,300° Fahr. it might be so much as 76 per cent. The cost of the process, including all charges, is given as 0·5*d*. per 1,000 cubic feet of gas treated.

THE CARPENTER-EVANS PROCESS

The Carpenter-Evans system of hot purification is in many respects similar to that described above, but differs in one very important particular, and that is the working temperature employed. The chemical reaction occurring is precisely similar to that taking place in the Oregon process, but the velocity of reaction is greatly increased by the adoption of a suitable catalyst. Consequently extremes of temperature are not needed. The process, which is now assuming some importance in this country, is carried out on the following lines: The gas is first heated up to about 770° Fahr. by passage through tubular heat-interchangers, and afterwards through a 6-inch tube placed within the furnace. The gas then passes into chambers containing a catalysing agent, wherein the carbon disulphide is converted into sulphuretted hydrogen and free carbon—

$$CS_2 + 2H_2 = 2H_2S + C.$$

The catalytic agent employed consists of fireclay balls about 1 inch in diameter impregnated with nickel reduced from the chloride, the apparatus being maintained at a temperature of about 800° Fahr. The heated gas, on leaving the catalyser, passes through a special heat interchanger in which it gives up part of its heat to the inflowing cool gas. The purified gas is then reduced to atmospheric temperature, and, finally, the sulphuretted hydrogen from the above reaction is removed by oxide of iron in the usual manner. The free carbon is left behind in the catalysing apparatus, and after about thirty days' run it is necessary to remove it. This is done by the process known as "aeration."

In order to regenerate the material of any distinct unit the temperature is permitted to drop, and air is pumped at a definite rate through the tubes containing

the catalyst. This process usually occupies about a week, and consists in burning out the deposit of free carbon, which travels away as CO_2. During the first four days of aeration the air is deprived of the whole of its oxygen. When once oxygen makes its appearance in the effluent products the temperature of the chamber is raised to 800° Fahr., and this temperature is maintained until carbon dioxide ceases to be evolved, when the process is complete. Some precaution is necessary when preparing for aeration, or when recommencing purifying after aeration has taken place. The tubes will contain either gas or air as the case may be, and the formation of an explosive mixture is prevented by passing in a current of inert waste gases collected from the furnace chimney. In this way the gas or air is displaced by nitrogen and carbon dioxide. The original activity of the catalyst is immediately restored by the aeration process.

E. V. Evans, the co-inventor, has pointed out that in a system of this kind it is necessary, for effective working, to bear in mind the following salient points—

1. The temperature of the gas should be raised to that of the reaction before coming in contact with the catalyst.

2. There must be a sufficiency of surface area of catalytic material exposed per unit volume of gas passed.

3. The reaction is affected by the porosity, specific heat and thermal conductivity of the porous carrier of the catalyst, and also by the volume of free space allowed between the contact surfaces.

4. The presence of sulphuretted hydrogen in the gas before treatment decreases the efficiency of the process, which cannot, therefore, be advantageously applied to crude gas. It seems probable that carbon oxysulphide is produced by conducting gas containing carbon monoxide and sulphuretted hydrogen over the catalyst—

$$(1)\ SH_2 = H_2 + S \qquad (2)\ CO + S = COS.$$

Ammonia is to be found at the outlet of the plant, and results from the hydrolysis of hydrocyanic acid, which occurs on the lines described in the previous chapter (*see* page 378). The inventors point out that although this ammonia is too small in quantity to represent a financial asset, it serves a useful purpose in maintaining the oxide of iron used to remove the sulphuretted hydrogen (formed by the decomposition of the CS_2) in a strongly alkaline condition. Practically the whole of the oxygen is removed by the process, but there is neither increase nor decrease in the volume of gas. So far as the effect on the general composition of the gas is concerned, Dr. Carpenter has given the following figures—

Analysis of Gas.	Before Treatment.	After Treatment.
CO_2, per cent. by volume	1·44	1·45
Heavy hydrocarbons	3·55	3·63
Oxygen	0·33	0·06
Carbon monoxide	8·16	8·03
Methane	26·85	27·26
Hydrogen	54·19	54·25
Nitrogen	5·48	5·32
Illuminating power	14·7	14·7
Calorific power, B.Th.U. gross	590·0	594·4

A complete view of the plant, with explanation of the working, is shown in Fig. 279. The plant illustrated is that in operation at the East Greenwich works of the South Metropolitan Gas Company and consists of five units each capable of dealing with three million cubic feet of gas per day. Each unit is provided with a producer (*A*) and a combustion chamber (*B*). On either side of the combustion chamber are the heating chambers (*C*), which contain the reaction tubes (*F*). The gas (purified from SH_2) enters the plant by a main (*H*) and passes into the heat interchangers (*G*). The last-named vessels are constructed on the lines of a multitubular boiler,

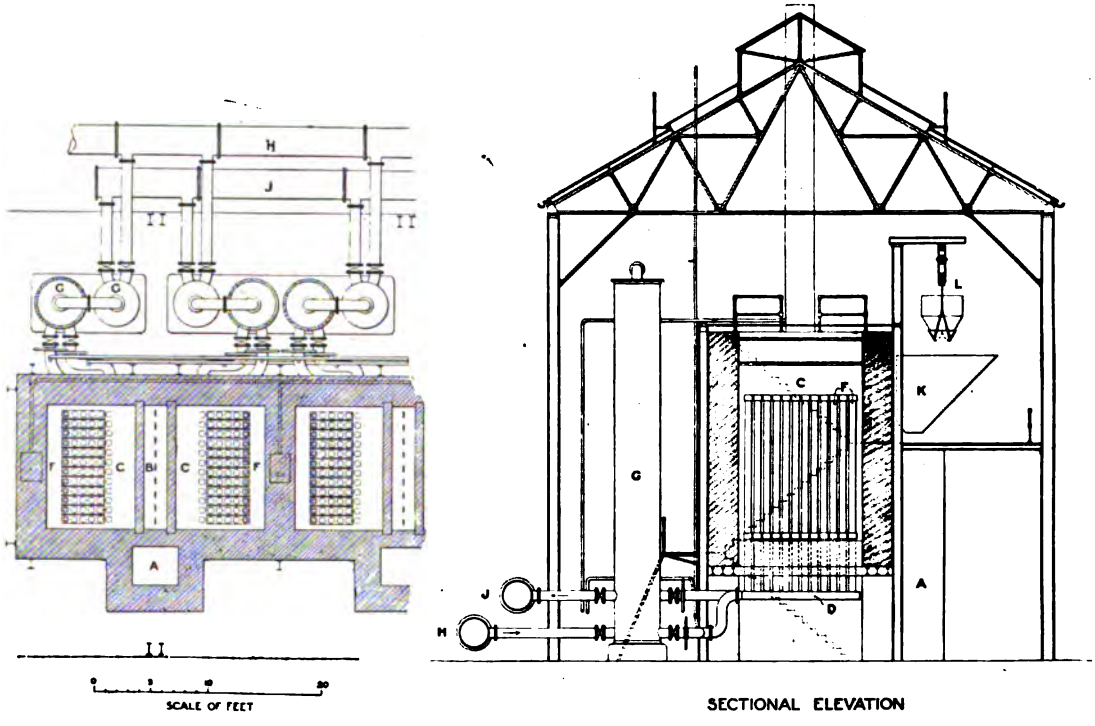


FIG. 279.—THE CARPENTER-EVANS HOT PURIFICATION PLANT.

A Furnace, *B* Combustion Chamber, *C* Heating Chamber, *D* Collector Tube, *F* Tubes containing Catalyst, *G* Heat Interchangers, *H* Gas before treatment, *J* Gas after treatment, *K* Coke Hopper, *L* Coke Handling Plant.

being filled with 3-inch tubes. The hot gas leaving the plant passes through the heat interchangers in the opposite direction to that of the inflowing gas, and in this way gives up a large proportion of its heat to the cold untreated gas. The gas is further raised in temperature in the heating chambers, and then flows in parallel currents through the tubes containing the catalyser, passing thence to the collector tube (*D*) and through the heat interchangers. After undergoing treatment in this manner the gas will usually contain about 20 to 30 grains of sulphuretted hydrogen per 100 cubic feet. This is removed by a series of secondary purification vessels (two in number at East Greenwich) containing oxide of iron.

According to Dr. Carpenter the 15 million cubic feet plant consumes 5½ tons of coke per day in the furnaces, this being fed into the producer by a hopper (*K*) which receives its supply from a telpher (*L*). The average cost of ridding the gas of its carbon disulphide in this manner amounts to rather less than one-third of a penny per 1,000 cubic feet. The expenditure is accounted for as follows—

Fuel (coke at 15*s.* per ton)	0·099	pence per 1,000 cubic feet.
Labour, conveying, clinkering, etc.	0·058	„ „ „ „ „
Supervision	0·011	„ „ „ „ „
Power	0·003	„ „ „ „ „
Wear and tear	0·030	„ „ „ „ „
Interest and depreciation (10 per cent.)	0·098	„ „ „ „ „
Total	0·299	„ „ „ „ „

The total capital expenditure for a large plant is in the neighbourhood of £1,500 per million cubic feet per day. As regards efficiency of extraction, the proportionate reduction is somewhat higher when a gas containing a larger amount of CS_2 is dealt with. The following results illustrate the average effect obtained—

Sulphur Compounds—Grains per 100 cubic feet.		Reduction, per cent.
Before.	After.	
63·78	10·34	83·8
19·21	5·34	72·2

THE ABSORPTION OF CS_2 BY AMINO COMPOUNDS

As explained beforehand, carbon disulphide may be absorbed by means of certain compounds such as aniline, when sulphuretted hydrogen is evolved and a somewhat complex organic residue remains. It has been stated that the reaction takes place on lines such as the following—

$$2C_6H_5NH_2 + CS_2 = (C_6H_5NH)_2CS + H_2S.$$

The carbon disulphide is thus precipitated in the form of a solid, namely, thiocarbanilide. The outstanding difficulty would appear to be the loss of the amino compounds by volatilization. This loss may, however, be curtailed by washing the gas with weak acids, but the cost of the process renders it prohibitive for use on a working scale.

THE LIMING OF COAL

The treatment of coal by adding lime to it in the retort is by no means novel, for it was attempted in the earliest days of gas lighting. The use of lime for this purpose did not, however, become anything like general, and any advantages which may result from the process seem to have been lost sight of for a long time, until, in 1882, W. J. Cooper was granted a patent relating to the treatment of coal in this way. Cooper claimed substantial advantages for his system, amongst others an enhanced illuminating power, a better coke, less impurities, and more ammonia.

Present-day interest in coal-liming is chiefly attached to the method as carried on at Cheltenham Gas Works, and with which the names of R. O. and J. Paterson are particularly associated. Liming at Cheltenham was first practised in the early eighties, and in spite of the repeal of the sulphur restrictions in 1906, the process, though dropped for a time, was re-introduced in 1910. In its modern form the system consists in admitting to the coal, just prior to its entering the breaker, a small proportion of caustic lime. In order that the liming effect may be uniform a small steam jet is allowed to play on the coal as it falls from the breaker. In this way the lime is fixed to the surface of the coal, giving each small particle of coal a regular coating. A further quantity of steam, introduced at the overhead retort-house hoppers, completes the fixing process.

So far as results are concerned, it is of interest to note that at Cheltenham the sulphur compounds were reduced to a steady average of about 21½ grains per 100 cubic feet of gas. The yield of gas per ton of coal advanced by over 800 cubic feet, whilst the sulphate of ammonia showed an increase of 1·88 lb. per ton of coal. The quantity of lime employed varies from 1·5 to 2 per cent. of the weight of coal carbonized, and it is estimated that of the total quantity 75 per cent. remains behind in the coke.

The intermixture of lime with coal is adopted on gasworks, not with a view to increasing the make of gas and other products, but primarily for the purpose of curtailing the sulphur compounds in the finished gas. The manner in which this object is attained is not wholly understood, the reaction, both chemically and physically, taking place on extremely complex lines. It has been suggested that the addition of lime is followed by a decrease of sulphur compounds in the gas, but a corresponding increase may be noted in the sulphur contents of the other products, chiefly the coke. Possibly the presence of the lime merely curtails the formation of CS_2, the gaseous sulphur being evolved almost wholly as sulphuretted hydrogen. Moreover, if CS_2 were evolved, the lime, acting as a catalytic agent, might account for its partial decomposition into SH_2.

THE "ATHION" PROCESS

The "Athion" process is of some importance so far as Continental practice is concerned; but at present it is unknown in this country. The gas, after being deprived of tar, ammonia and sulphuretted hydrogen, is washed with a solution of potassium carbonate, in order to effect the complete removal of carbon dioxide. The potassium carbonate, by the absorption of carbon dioxide, is converted into the bicarbonate, and when the solution of the latter is boiled, the salt is reconverted into the simple carbonate, carbon dioxide being expelled. The potassium carbonate solution acts, therefore, in a continuous cycle. After being saturated with carbon dioxide in the washers, it is deprived of it again by boiling, cooled, and sent back to the washers. The removal of CO_2 in this way is necessary, otherwise the remainder of the process for the extraction of the sulphur compounds is rendered ineffective. The carbon disulphide is taken up by the "Athion" material, which is an alkalinated

cellulose—that is, a compound of alkali and cellulose, obtained by treating cellulose sulphite with soda lye. The material thus produced is subjected to rolling and crumbling, afterwards being spread on purifier grids in the ordinary manner. The carbon disulphide, on combining with the material, then converts it into xanthogenate of cellulose (viscose), the latter product being of use in the manufacture of non-inflammable celluloid. The inventors claim that with English coal the sulphur compounds are reduced from 30·75 to 7·87 grains per 100 cubic feet, or a reduction of 75 per cent. Ten tons of the special material absorb 1¼ tons of carbon disulphide, and it is thus calculated that 10 tons would purify 35,000,000 cubic feet of gas

CHAPTER XVII

THE STORAGE OF GAS

Of the various portions of apparatus commonly found on gasworks, that made use of for storing the finished gas prior to its delivery to the supply area accounts for the greatest individual outlay. In normal instances, from one-quarter to one-third of the total capital expenditure on the works will be absorbed by the storage plant, whilst the ground area covered by this plant will amount roughly to some 20 per cent. more than that required for retort houses and coal stores combined.

Since the introduction of gas as an illuminant the same principle, that of a floating vessel rising and falling in a seal of water, has been embodied in all storage apparatus; and although suggestions for replacing the gasholder by some less cumbersome contrivance have, from time to time, been brought forward, they have not as yet materialized in practice.

The quantity of gas which it is desirable to hold in reserve at the works is chiefly dependent upon the fluctuation of the daily load curve. During recent years the hourly consumption has tended to become more and more regular, with a consequent levelling out of the curve. For this reason, the necessary holder capacity has undergone reduction; and it has been suggested that, in the future, storage will be practically unnecessary, once the daily curve of consumption has been straightened out altogether. It must be remembered, however, that one of the most important functions of the gasholder is the provision it affords against breakdown, and it would seem that the day of gasworks without this familiar apparatus is still far distant. With present-time conditions it may be assumed that the maximum hourly consumption is approximately arrived at by dividing the maximum daily output by 22. The amount of storage provided will not only be influenced by the nature of the supply, that is, whether chiefly lighting, power or cooking, but by the facilities at the works for meeting fluctuating demands with a similar variation in the quantity of gas produced.

It is in the latter respect that a water-gas plant, capable of being started up or dropped at short notice, proves of value. Accordingly, in instances where the daily load curve is moderately constant, and where the peak of the load may occur during the daytime, the storage provided may be safely reduced to 16 or 18 hours' maximum production. On works in which no surplus water-gas plant (or no water-gas plant at all) is available the capacity of the holders should be increased to from 21 to 24 hours' maximum "make." As has already been pointed out in Chapter I, storage capacity on the daily "make" basis is decidedly elastic; for when an extra holder

is erected on a works, it is invariably the largest. Consequently, before the new holder is put into operation the storage is deficient; whilst, once it is at work, the storage may be excessive, provision being made for the future.

When building a new works, or when adding to the capacity of an older works, it should be borne in mind that future development must be expected, and that the most ready and economical way of meeting this is to make arrangements for the addition of a further (outer) lift in the future. The holder tank in such cases is constructed of sufficient size to contain the extra lift, and in this way capacity may

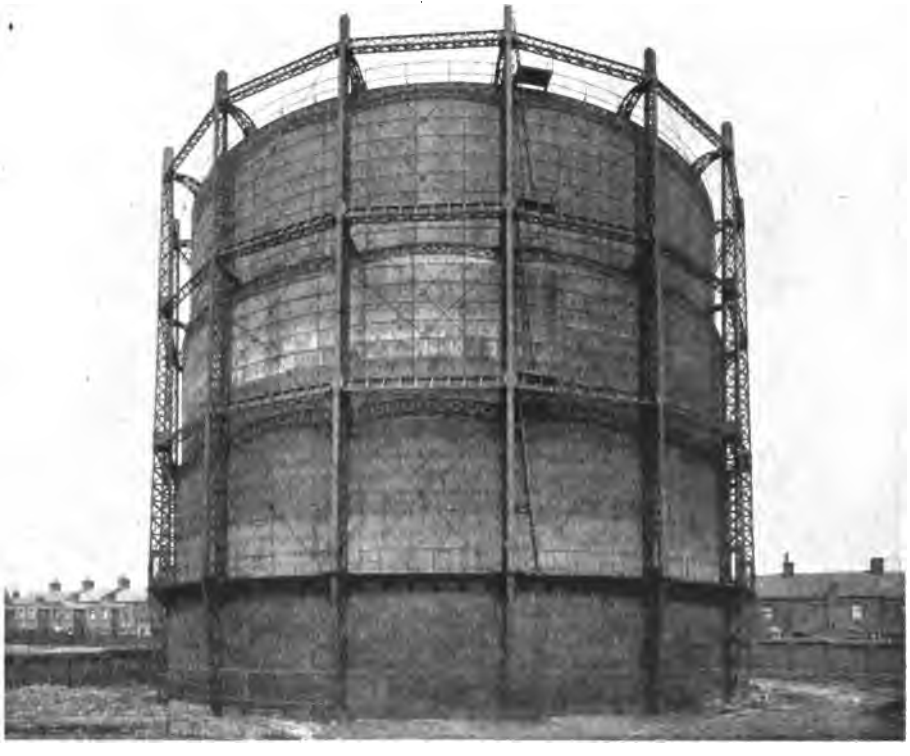


FIG. 280.—TELESCOPIC HOLDER WITH BRACED GUIDE-FRAMING.

be increased by from 50 to 100 per cent. for a comparatively small outlay. If the holder is of the ordinary guided type the top section may be converted into a "flying-lift" when the new bottom lift is added, or, alternatively, the guide-framing may be carried up to suit. For this reason the spirally guided holder, having no distinct guide framing, lends itself more readily to extension, although prior to the insertion of the extra lift the tank will be subjected to additional stressing owing to the increased "overhang" of the guide roller carriages. Needless to say, the effect of this loading should be carefully considered when the tank is being designed. The addition of an extra lift cannot be contemplated if the holder represents the

principal storage unit, for the time required to complete the alteration would be at least from five to six weeks, and might amount to three or four months.

THE VARIOUS TYPES OF GASHOLDERS

The chief distinction between the various forms of holders is to be found, not so much in the formation of the floating bell but in the manner adopted for guiding the bell, and in the construction of the tank containing the water. The function of the water is primarily that of providing an elastic gastight seal in which

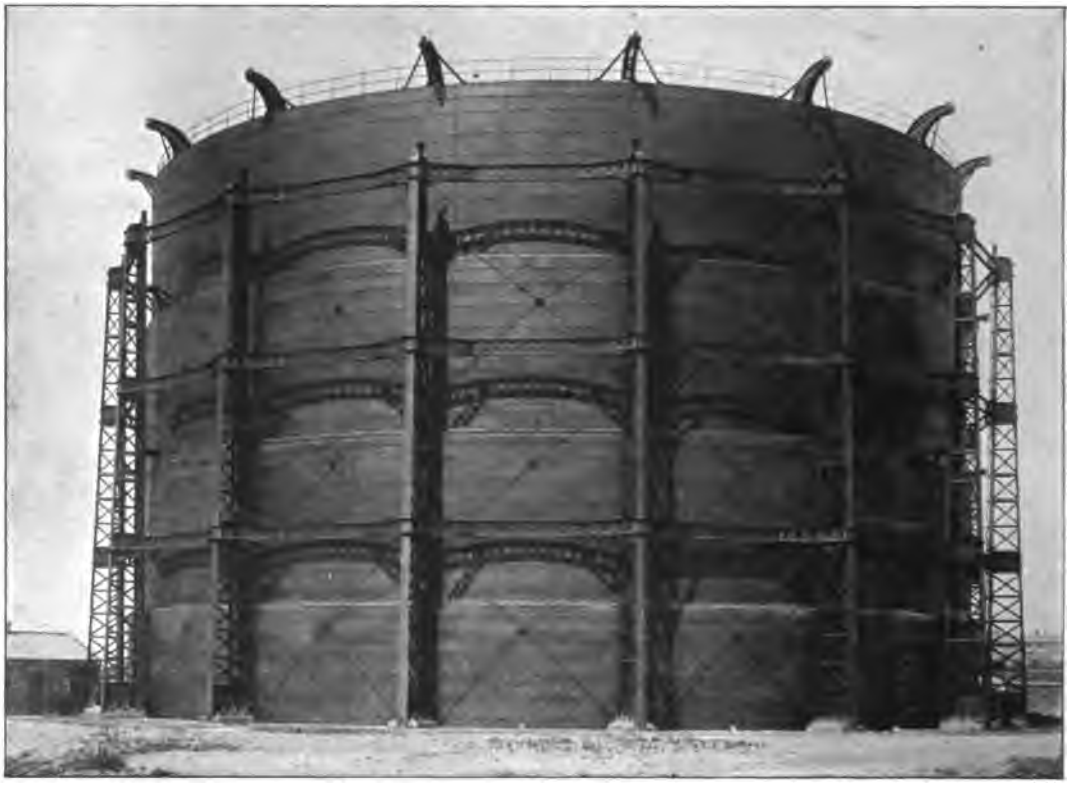


FIG. 281.—TELESCOPIC HOLDER WITH FLYING LIFT.

the bell may rise or fall; in addition, it receives the whole of the pressure thrown by the weight of the bell, and in this way forms the necessary resistance by means of which the bell is raised or the gas expelled.

In the first instance gasholders may be generally classified under two distinct headings:—

1. Simple holders, in which the bell consists of one section or "lift" only.
2. Compound holders, in which the bell is composed of two, or a number of "lifts," arranged to telescope one into another when the holder is empty, or partly so.

More broadly classified, the various descriptions of holders may be set down as follows :—

1. Holders guided by wire cables.

2. Holders guided by ordinary distinct vertical guide-framing, with or without "flying lifts."

A typical holder with braced guide-framing is shown in Fig. 280. A telescopic holder with "flying" lift is seen in Fig. 281.

FIG. 282.—SPIRALLY GUIDED HOLDER.

3. Spirally guided holders (left or right hand, or a combination of both). The guides, so far as the bell is concerned, may be either internal or external. Fig. 282 shows a spirally guided gasholder.

4. Holders with a floating roof, generally known as the Nuremberg type.

The cable-guided holder, though of historical interest, can scarcely be con-

sidered under the heading of modern structures. Holders of this type are still in use, the largest of the kind being in operation at Middlesbrough.

This holder has three lifts (the outer of which is 185 feet in diameter) and a total capacity of 2¼ million cubic feet. Theoretically, at least three cables are necessary for a single-lift holder. One extremity of each is attached to the upper edge of the tank, the cable is then led round a pulley fixed to the top curb of the gasholder and afterwards passes over the top of the bell to a second pulley attached to the top curb at a distance of about one-third of the circumference from the first pulley. The cable is then led downwards and around a third pulley fitted to the bottom curb of the holder, its other extremity being fastened to the top of the tank. Thus, as the bell rises or falls each cable is maintained in a taut condition.

THE DESIGN OF GASHOLDERS

By far the most common type of gasholder is the single or multiple "lift" vessel guided by a number of columns spaced circumferentially around the top of the tank at distances of from 15 to 30 feet apart. The columns are adequately braced together by horizontal girders and diagonal ties, the girders for large holders being built up from steel sections, whilst the ties (which are in tension only) may be made from plain round or flat steel bars. In the past, it was customary to erect massive cast-iron columns which carried a guide rail and ensured the rigid guiding of the holder. A heavy cast-iron or a wrought-iron trellis cross girder extended from apex to apex of the columns, whilst tie-rods of unusual length completed the framework. To-day, the cast-iron frame has been entirely superseded by that composed of comparatively light columns constructed from rolled mild-steel sections. For the smaller holders (say up to 750,000 cubic feet capacity) the standards may advantageously be plain H joists at centres of from 15 to 18 feet, stayed up by a smaller size of the same section for the horizontal cross struts. Each panel would then be tied together by circular rods arranged diagonally, and meeting in the centre of the panel. At the junction of the ties a centre ring, permitting of adjustment, may be used, but modern practice tends towards adjustment at the standards. Centre rings, moreover, are inclined to spring, and are often absurdly weak in comparison with the bars. Particulars of the guide framing for a holder of this kind are given in Fig. 287 (page 433).

For larger holders the necessary size of a single rolled section for the upright stanchion would not conduce towards economy or comeliness; accordingly, it is customary to build up the columns on the principle of the lattice girder, the horizontal cross-girders being designed on the same lines. As a general rule, it may be said that single H joists may be used for the vertical columns so long as their depth is not found (after the necessary calculations for stability have been made) to exceed 18 inches. When joists are employed their total height from tank level should not be greater than 65 times their cross-sectional depth.

THE PROPORTIONS OF GASHOLDERS

The preliminary operations in designing a gasholder are to ascertain the required capacity; and, this being done, to determine upon the diameter and height of the

bell, the number of lifts, etc. In calculating the capacity of holders the space enclosed by the domed top is neglected, owing to the fact that the gas in this portion is never expelled. The volume enclosed by the domed space is, therefore, ineffective. For preliminary calculations the size of the holder may be arrived at by applying the simple formula :—

$$\text{Capacity in cubic feet} = \cdot 7854 \times (\text{diameter})^2 \times \text{height}.$$

For a single-lift holder this calculation will suffice, but when a multiple-lift holder is under consideration the capacity of the separate lifts should be distinctly estimated by applying the above rule to each section, due allowance being made for the cups.

CONSIDERATIONS AFFECTING THE PROPORTIONS OF GASHOLDERS

There are many factors by which the general proportions of gasholders are influenced. Chief amongst these are :—

(*a*) The nature of the sub-soil, and, therefore, the design of the tank.

(*b*) The ground space available for construction.

(*c*) The pressure required to be thrown by the holder if "boosting" is not to be resorted to.

If the ground space available is unlimited the constructor is not hampered in having to curtail diameter, with a consequent increase in height, although deep lifts may be necessary in order to obtain the necessary pressure. Deep lifts give rise to more costly tanks, although a saving may be effected by arranging for one lift less than the number which might ordinarily be inserted, thus economizing on the total number of cups and grips, these accounting for a considerable item in the outlay. When the erection of a holder is contemplated, it is an excellent plan to consider two suitable propositions entailing different proportions, with a view to taking out quantities for both. The following figures, which show, very approximately, the weight of metal employed in the construction of two types of gasholders of identical capacity ($1\frac{1}{4}$ million cubic feet), will serve to illustrate the point :—

	Four-lift Holder.	Three-lift Holder.
Ratio $\frac{\text{Depth of top lift}}{\text{Diameter}}$	0·18	0·21
„ $\frac{\text{Total height}}{\text{Diameter}}$	0·64	0·50
Weight of steel tank	336 tons	405 tons
„ crown rest framing	52 „	63 „
„ guide framing	230 „	223 „
Total, tank and framing	618 tons	691 tons
Top lift	128 tons	146 tons
Second lift	68 „	80 „
Third lift	68 „	74 „
Fourth lift	60 „	—
Weight of bell	324 tons	300 tons
Total weight	942 „	991 „

It will be seen that the four-lift holder shows some considerable saving, chiefly in the construction of the tank, in weight of metal, and therefore in expenditure.

The depth and diameter of the various lifts of gasholders are readily arrived at by any one of experience, the following being the usual proportions adhered to :—

Ratio of Height to Diameter of Holder

For single-lift holders the height varies from 0·3 to 0·4 of the diameter. With telescopic holders the normal proportion varies between 0·6 to 1·0 of the mean diameter. In both cases the figure given refers to the height of the bell only, and does not include the depth of the tank.

Depth of Lifts

Each lift will be *approximately* of similar depth ; i.e. the depth of each is equal to the total height of the bell divided by the proposed number of lifts, due allowance being made for the depth of cups and grips.

Diameter of Lifts and Size of Cups

For the smaller holders the width of the cups should be 8 inches. Medium sized and larger holders are preferably provided with a 10-inch cup, although in the case of the largest sizes 12 inches is occasionally found. It will be understood that the diameter of the second lift is greater than the diameter of the top lift by an amount equal to three times the width of the cup ; the diameter of each succeeding lift increasing by the same amount. The depth of the cups must be such as to carry a water seal sufficient to withstand the maximum pressure thrown by the holder. In general, it may be said that no telescopic holder would be provided with cups less than 16 inches deep, whilst for the largest holders the figure would not exceed 24 inches.

Rise of Crown

The rise given to the domed crown of a holder varies in accordance with the stresses induced ; the greater the rise, the stronger the crown. The dome should in all cases conform to a segment of a sphere. Normally, the rise will lie between $\frac{1}{15}$ to $\frac{1}{20}$ of the diameter (though seldom $\frac{1}{15}$), a greater pitch being given when no trussing is employed. The cubic capacity of the crown space may be found as follows :—

$$\text{Volume (in cubic feet)} = 0{\cdot}5236\ \text{R}\left(\text{R}^2 + \frac{3\text{D}^2}{4}\right)$$

Where R = Rise of crown in feet
and D = Diameter of holder in feet (top lift).

Proportions of Lifts

The ratio of the depth of a lift to its diameter varies to some considerable extent, but it has been laid down by Cripps as a working principle that the depth of the lift must never be less than one-seventh of its diameter, otherwise tilting is extremely likely to occur. In ordinary practice the proportion varies from one-fourth to one-fifth of the diameter.

THE GUIDE-FRAMING OF GASHOLDERS

The author takes this opportunity of pointing out that the knowledge we have of the stresses and strains in gasholder structures at the present day is almost solely built up from the theories expounded by the late Sir Benjamin Baker and by Mr. F. Southwell Cripps. The latter has published an eminently practical and scientific treatise—now unhappily out of print—which has for long been and still remains the standard work of reference on the subject. The treatment adopted by the author in the following pages—so far as the stresses in the guide-framing and top curb are concerned—is, for the most part, a reiteration of the deductions and methods of Mr. Cripps, as set forth in his work entitled, "The Guide-framing of Gasholders, and other papers chiefly relating to the strains in structures connected with Gas-Works."

The stresses occurring in the guide-framing of a gasholder are occasioned by pressure of wind and snow. The weight of the members themselves will, however, give rise to certain loading, and this effect must not altogether be neglected. In calculations of the kind it is customary to assume a wind pressure equal to a maximum of

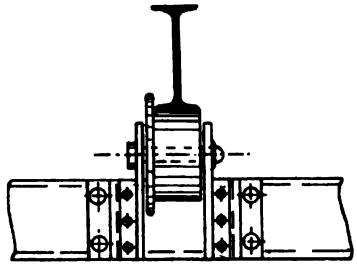


FIG. 283.—RADIAL GUIDE ROLLER.

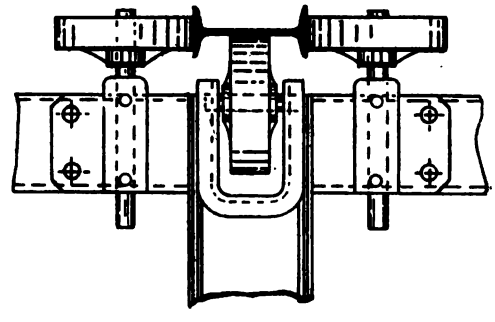


FIG. 284.—TANGENTIAL GUIDE ROLLERS.

32 lb. per square foot, but owing to the surface on which the pressure is received being rounded, the usual 50 per cent. reduction may be assumed—thus giving an effective pressure of 16 lbs. per square foot on the diametrical projection. Primarily it must be understood that the wind and snow pressure is received by the holder bell, and, by means of the guide-rollers, it is transmitted to the upright standards, which are braced together in such a manner as to withstand distortion and any tendency to capsize. The manner in which the stresses are transmitted to the framing is chiefly dependent upon the system of guide-rollers adopted; i e. whether the rollers are radial, tangential, or a combination of both. The ordinary radial roller is shown in Fig. 283. Fig. 284 shows a combination of the radial and tangential methods.

For the purposes of calculation, the whole of the guide-framing may be regarded an an immense cylinder, receiving partial stiffening from a light internal ring (the bell itself). If we consider a simple holder with radial guide rollers subjected to wind pressure in one direction it is plain that there is a tendency for the bell to press hard up against those columns on the leeward side. Owing to the provision of

horizontal struts and diagonal ties between the columns this stress is, in the modern form of holder, transmitted throughout the whole framework, and not merely to a portion of it. If tangential rollers are employed in addition to radial guides the pressure will come directly on to about one-half of the total number of columns; but when radial rollers alone are used, one-quarter of the columns must be considered as directly loaded. As stated above, however, the remainder of the framework will, indirectly, be taking its share of the load.

As the vertical columns are fixed at one end only (i.e. to the top of the tank) the whole framing may be looked upon as a girder acting in the capacity of a huge cantilever. A simple cantilever when loaded tends:—

1. To shear off at the point of support.

2. To undergo distortion due to the bending moment. Hence, the vertical columns have a tendency:—

1. To shear off at the base and overturn.

2. To bend and become distorted, thus causing some deformation of the true cylindrical form of the guide-framing.

The first condition applies to the frame structure as a whole, whilst the second affects each column individually in accordance with the wind pressure on any particular section.

The general proportions and scheme of design (such as height, diameter, and probable number of standards) of the holder being known, the first step in the calculations is that of determining the maximum stress likely to be met with in each standard.

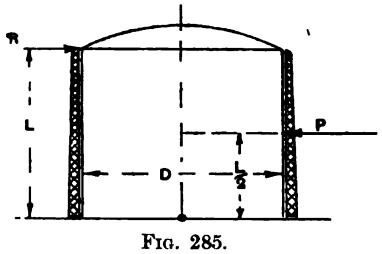


FIG. 285.

WIND PRESSURE

Consider a common form of gasholder having guide-framing extending to the full height of the bell.

Let L = total length of columns, which in this case is the same as the height of the bell (in feet).

Let D = mean diameter of bell (in feet).

,, P = Wind pressure (total force) in lbs.

The wind pressure P acts at the centre of pressure of the bell, i.e. at a distance half-way up from the base. Therefore, the overturning moment

$$= P \times \frac{L}{2}$$

but P = total wind pressure.

i.e. 16 lbs. per sq. foot on an area of L × D sq. feet

$$\therefore P = 16LD$$

or, the overturning moment $= 16LD \times \frac{L}{2} = 8L^2D$.

This moment is resisted by the reactionary force R at the top of the guide framing, and the moment of the reaction

$$= R \times L$$
$$\therefore R \times L = 8 L^2 D$$
$$\text{or } R = \frac{8 L^2 D}{L} = 8 L D$$

i.e. the overturning force due to the wind amounts to 8 LD.

Snow Pressure

Snow pressure may be considered equal to 5 lbs. per square foot on one-fourth of the area of the dome, and acting at a point of one-sixth the diameter from the top curb.

Then if W_s = the total weight of snow, this acts at a distance of $\frac{D}{6}$ from the edge, or $\frac{D}{3}$ from the centre of the bell.

To find total weight of snow :—

Total area of dome $= \cdot 7854\, D^2$

$$\therefore \text{Portion covered by snow} = \frac{\cdot 7854\, D^2}{4}$$
$$\text{or weight of snow} = \frac{\cdot 7854\, D^2}{4} \times 5$$
$$= \cdot 981\, D^2 \text{ lbs.}$$

(0·981 is very nearly 1, and for the purposes of calculation Cripps considers that it may be assumed equal to 1.)

Therefore, total weight of snow $= D^2$ lbs.

Now the snow gives rise to a tilting moment.

$$W_s \times \frac{D}{3} = D^2 \times \frac{D}{3}$$
$$\text{or } \frac{D^3}{3}$$

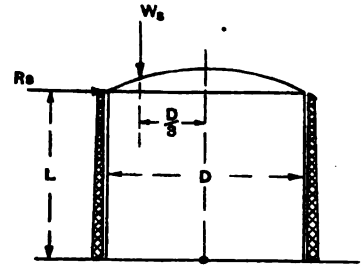


Fig. 286.

This moment is resisted by the reaction R_s at the top of the columns, and the moment of the reaction $= R_s \times L$

$$\therefore R_s \times L = \frac{D^3}{3}.$$
$$\text{or } R_s = \frac{D^3}{3L}$$

Considering the results of wind and snow together we see that the total reaction in the structure, that is the total force it has to resist is :—

$$8LD + \frac{D^3}{3L}.$$

Accordingly, the bending moment on the structure will amount to

$$L\left(8LD + \frac{D^3}{3}\right) = 8L^2D + \frac{D^3}{3}$$

and the section modulus must be made of such dimensions as to withstand this bending moment.

The sectional dimensions of the columns are calculated from the well-known formula

$$\text{Bending moment} = f_{\max} Z$$

where $f_{\max.}$ is the maximum allowable stress in the steel, i.e. 6 tons per square inch for ordinary steelwork,

and Z = the section modulus, or $= \frac{I}{Y}$

Where I = the total moment of inertia of the structure,
and Y = half the depth of the section.

It must here be borne in mind that we are dealing with a cantilever composed of the structure as a whole, and not with an isolated column. Therefore, in arriving at the value for Z—

$$Y = \text{half the total diameter of the holder} = \frac{D}{2}.$$

The moment of inertia I can be found by the summation of the elements, using the ordinary formula.

$$Ix = Io + AD^2$$

Where Ix = the moment of inertia of each element about the true neutral axis of the section.
Io = the moment of inertia of each element about its own neutral axis.
A = the area of the element.
D = the distance of its neutral axis from the true neutral axis.

This formula is, however, somewhat tedious ; and, although not strictly accurate, Rankine's formula is very much more easily handled.

The formula says :—

$$Z = 0{\cdot}25\ NAD.$$

Where N = number of the columns.
A = cross-sectional area of each column in square inches.
D = diameter of holder in feet.

Then, having found the value of Z it is possible to equate this to the bending moment in the ordinary way :—

$$\text{Bending moment} = f_{\max.} Z.$$

(It must be noticed that the wind pressure P was taken in lbs., and the allowable stress f_{max} is in tons. The two must therefore be reduced to equivalent units.)

From above :—

$$8\,L^2D + \frac{D^3}{3} = 6 \times 2240 \times 0{\cdot}25\,N\,A\,D.$$

$$\text{or } A = \frac{8\,L^2D + \frac{D^3}{3}}{6 \times 2240 \times 0{\cdot}25\,N\,D}$$

$$= \frac{24\,L^2 + D^2}{10{,}080\,N}$$

$$\text{or (very nearly)} = \frac{24\,L^2 + D^2}{10{,}000\,N}.$$

The area A given by this formula is the cross-section of each column necessary to prevent failure of the structure as a whole.

Bending moment on one bay only.

Consider the standard as a beam supported at both ends and uniformly loaded. Then if—

B = the pitch of the columns in feet.

L = the total length of each column.

The bending moment $= \frac{wl^2}{8}$, where w = the load per foot run. Working on the assumptions of Cripps, it is customary to consider the wind pressure equal to 10 lbs. per square foot, which is assumed as acting upon a length of standard equal to three-quarters of the depth of the holder. In the above formula, therefore, we have,

$$w = 10 \text{ lbs. per sq. foot, and } l = \frac{3}{4}\,L.$$

$\therefore$ Bending moment (B_b)

$$= \frac{10 \times B \times (\frac{3}{4}L)^2}{8 \times 2240} \text{ tons-feet.}$$

$$= \text{(approximately) } \frac{B\,L^2}{270}$$

The bending moment (B_b) on a single bay is, therefore, equal to—

$$\frac{B\,L^2}{270} \text{ inch-tons}$$

where B = the width in feet of one bay, i.e. distance from column to column and L = height of standard as before.

(This conclusion appertains only to those holders in which the guide-framing is carried the whole way up.)

Then $B_b = f_{max.}\,Z$

$$\text{or Z (the section modulus)} = \frac{B_b}{f_{max}}.$$

Knowing Z, the required area of the section of the column can be found from the following approximate formula :—

$$Z = 2Ay$$

Where A = the area of *each* flange of the column.

y = half the depth of the cross-section of the column.

$$\text{or, } A = \frac{Z}{2y}$$

(It will be noticed that this gives the cross-sectional area at the base, i.e. where the greatest stresses have to be withstood. The cross-sectional area may, of course, be reduced towards the top.)

In designing a column the total area required must be taken (i.e. formulae A + B).

$$\text{The total area} = \left(\frac{24\,L^2 + D^2}{10{,}000\,N} + \frac{BL^2}{3240y}\right).$$

(*Note.*—The value for f has been taken as 6 tons per square inch. Cripps, in order to allow a margin owing to the fact that the standard is acting as a column takes a value of 4 tons per square inch.)

The method of calculation will be readily understood by the consideration of a simple example.

Take a holder of such design as that seen in Fig. 287, having a capacity of about 750,000 cubic feet. Let the diameter of the bottom lift be 110 feet, and the total height of the bell (which is the same as the effective height of the standards) 80 feet. The standards will be conveniently spaced at a pitch of about 16 feet; or, as the tank circle will measure approximately 352 feet, it can be assumed that the standards will be 22 in number.

The total area required for each flange at the base of the standards

$$= \frac{24\,L^2D^2}{10{,}000\,N} + \frac{BL^2}{3240y}.$$

In the example under consideration :—

L = 80 feet

D = 110 ,,

N = 22 ,,

B = 16 ,,

y = half depth of cross-section in inches.

$$\text{therefore, area} = \left(\frac{(24 \times 80 \times 80) + (110 \times 110)}{10{,}000 \times 22} + \frac{16 \times 80 \times 80}{3240 \times y}\right)$$

$$\text{,, ,,} = 0{\cdot}75 + \frac{31{\cdot}60}{y}$$

Assuming a depth of 18 inches for the cross-section, $y = \frac{18}{2} = 9$ therefore area of each flange $= 0{\cdot}75 + \frac{31{\cdot}60}{9} = 4{\cdot}26$ sq. inches.

or total area of flanges = 8·52 sq. inches.

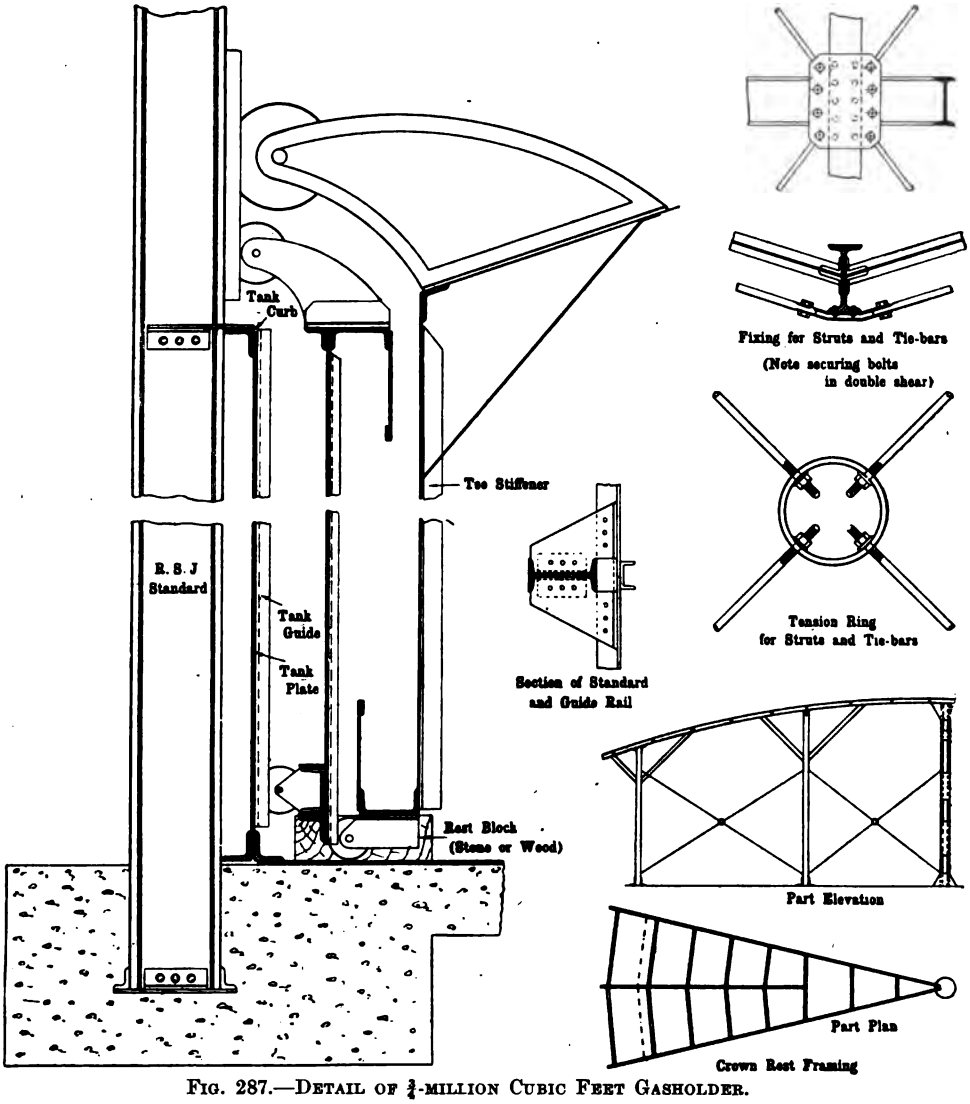


FIG. 287.—DETAIL OF ¾-MILLION CUBIC FEET GASHOLDER.

Considering a number of possible standard sizes of R.S.J. the following comparison may be made :—

	Size of Joist.	Weight lbs. per Foot.	Theoretical Area Registered (Both flanges).	Area Given	
	Inches		Square inches	Square inches.	
A	18 by 6	55	8·52	8·44	1 per cent. deficient
B	18 „ 7	75	8·52	13·5	excessive
C	16 „ 6	62	9·4	10·36	slight excess
D	15 „ 6	59	9·92	10·73	slight excess
E	15 „ 5	42	9·92	6·60	deficient

Choice should fall on the lightest section which fulfils the required conditions as to stability. Section A would, therefore, be decided upon, for the very slight deficiency would be more than compensated for by the metal in the web. Some designers might not care about a section so deep as 18 inches for a holder of this size, and if such is the case, that under heading D, though slightly heavier, might be conveniently employed.

It should be mentioned that with a rolled standard of this description some engineers base the required flange area on the figure given by the formula relating to the bending moment on the single bay only, delegating the remainder (i.e. the area required to resist the capsizing of the holder as a whole) to the web of the section. It is necessary to emphasize, however, that when a composite section of the lattice-braced type is adopted, no reliance must be placed in the web. For this reason, and also owing to the fact that a maximum stress of 6 tons per square inch has been taken, the author prefers to deal with all sections in the manner indicated above, so that when the web is of assistance a small increase is obtained in the gross factor of safety.

TYPES OF STANDARDS

The ultimate design of the standards must primarily be influenced by the calculation for area as shown above. Keeping this figure in view and bearing in mind generally accepted working precedents, it is possible to evolve a section combining a minimum of metal with a maximum of stability. For instance, the metal composing the flanges may (within certain limits) be reduced in proportion to the increase in depth of the section; in other words, the weight per foot run may be decreased as the depth becomes greater. So far as the plain H joist is concerned this possesses the disadvantage that it cannot be reduced in cross-section towards the top of the columns, thus considerable wastage of metal occurs. In spite of this, however, a joist will be found the most economical section for holders up to about $\frac{3}{4}$ million cubic feet capacity, owing to the comparatively small amount of labour involved, and in contrast to the expenditure under this item in connexion with standards of the built-up description. Also the plain girder will weather better and offers less chance of deterioration.

So far as the old-fashioned cast-iron columns are concerned it may be noted that gasholders designed on these lines cannot be treated as a braced cantilever, as is the case with the modern structure. In the old pattern each standard forms a cantilever in itself, and although horizontal girders, and in some instances, light diagonal ties, connect the columns together, it cannot be assumed that the framework is of such elasticity as to distribute the loading throughout the whole. Being of the rigid type each column takes the loading in accordance with the direction in which this may be imposed, and rigidity is obtained by employing a superabundance of dead weight. Fig. 288 shows the elevation of a number of forms of gasholder columns, both steel and cast iron. The cast-iron designs with pulleys for the chains of counterbalance weights are now out of date.

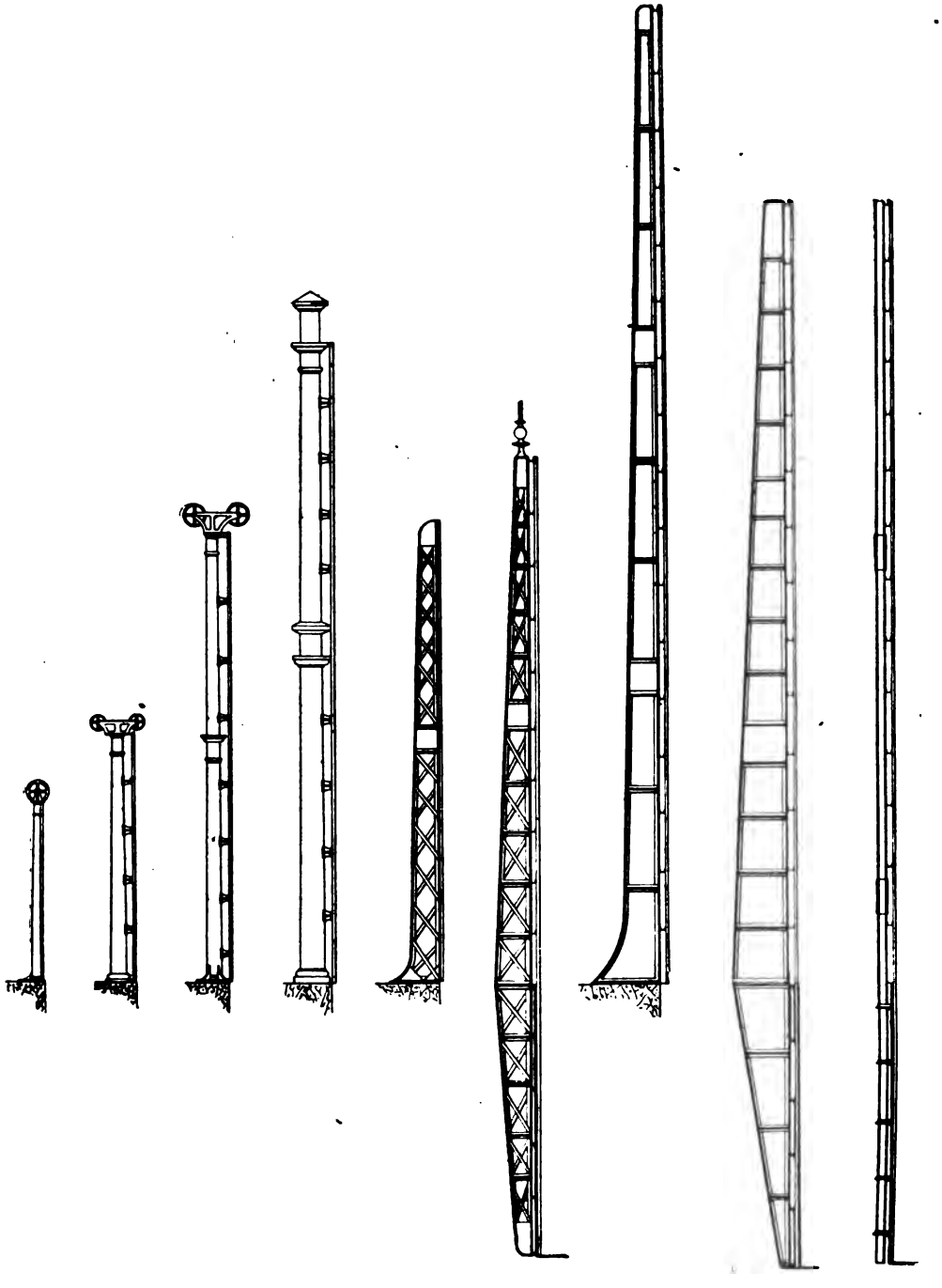


FIG. 288.—VARIOUS FORMS OF GASHOLDER STANDARDS.

DETERMINATION OF MAXIMUM SHEAR

Consider a braced cantilever as in Fig. 289.

Bending moment = WL, and this is resisted by Rd.

(taking moments about o)

$$\therefore \text{WL} = \text{R}d.$$

or R (which is horizontal shearing force at flange) $= \dfrac{\text{WL}}{d}$,

or, horizontal shearing force $= \dfrac{\text{Bending moment}}{\text{Depth of girder}}$.

The section we have to consider is a braced cantilever of cylindrical form, i.e. with no actual top and bottom flanges. Now the radius of gyration of a hollow cylinder about a pole passing through its centre is 0·707 D. Sir Benjamin Baker considered, therefore, that if the guide-framing was considered as an ordinary two-flanged girder the two imaginary flanges might be taken as occurring at the radius of gyration. F. S. Cripps, however, whose conclusions on matters relating to holders are accepted as final, states that, taking all things into consideration, the depth of the imaginary girder may be considered as $\frac{3}{4}$ of the diameter of the cylinder, i.e. 0·75 of the diameter of the holder, i.e. $\frac{3}{4}$D. Then we have an assumption such as that shown in Fig. 289, the depth of our girder being $\frac{3}{4}$D.

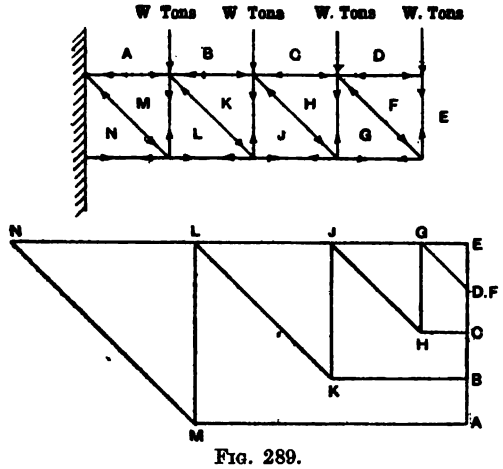


Fig. 289.

It has been shown above that horizontal shear $= \dfrac{\text{Bending moment}}{\text{Depth of girder}}$.

But it has already been shown that in the case of the holder framing (*see* page 430) the total bending moment is equal to :—

$$\left(8\,\text{L}^2\text{D} + \frac{\text{D}^3}{3}\right) \div 2240 \text{ ton-inches,}$$

and the depth of the girder $= \frac{3}{4}$D.

$\therefore$ Total horizontal shearing force

$$= \frac{\left(8\,\text{L}^2\text{D} + \frac{\text{D}^3}{3}\right) \div 2240}{\frac{3}{4}\,\text{D}}$$

It will be noticed that the plane of the shearing force cuts the framing in two points (such as O and P), consequently the shear on each of the horizontal planes will be half the total shear, or—

$$= \tfrac{1}{2}\left(\frac{\left(8\,L^2D + \frac{D^3}{3}\right) \div 2240}{\frac{3}{4}D}\right) = \frac{24\,L^2 + D^2}{10{,}080}$$

Cripps points out that sufficient accuracy will be obtained by taking this formula as—

$$\text{Horizontal shear} = \frac{24\,L^2 + D^2}{10{,}000} \text{ tons.}$$

(It will be noticed that the shear is spoken of as *horizontal*, for the reason that we are now considering a horizontal cantilever as shown in Fig. 289. In the case of the gas-holder the cantilever is in a vertical position, therefore the shear is *vertical* shear.)

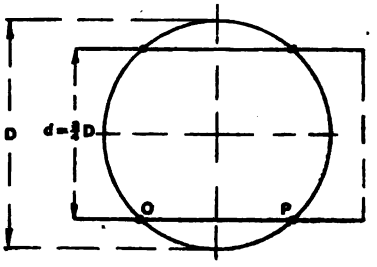


Fig. 290.

So far as computing the effect of the shearing-stress is concerned, Cripps has shown that although the loading on the standards is in reality concentrated at each roller contact, it may be considered as a distributed load, for the stiffness of the standards converts the forces given out opposite the rollers into a distributed load so far as the struts and ties are concerned.

THE STRESSES IN A BRACED CANTILEVER

The method of computing the stresses in the struts and ties of the guide-framing will readily be followed by considering an ordinary braced cantilever (Fig. 289) and the reciprocal stress diagram for the same. The equally distributed load will be apportioned amongst each of the nodes, the loads AB, BC and CD, being equal (W tons) whilst the end node carries $\frac{W}{2}$. If, however, we assume that each node carries an equal weight (not a strictly accurate assumption, but nevertheless approved by Cripps) it is easily seen from the reciprocal diagram that the stress in the diagonal ties and vertical struts increases from the end towards the abutment in the proportion 1, 2, 3, 4. Therefore, if we have the total horizontal shear it is possible to compute the stress in the struts and ties. For instance, if S_t is the total shear resolved in the direction of the ties, and S_s is the total

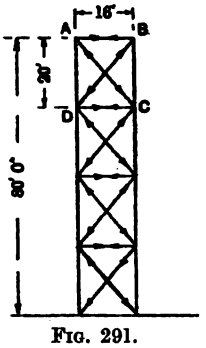


Fig. 291.

shear resolved in the direction of the struts—then, if we have four panels—

$$1+2+3+4=10$$

$$\therefore \text{ Tension in tie nearest abutment} = \frac{4}{10} \text{ of } S_t$$

$$\text{,, ,, tie in 2nd panel} = \frac{3}{10} \text{ ,, ,,}$$

$$\text{,, ,, tie in 3rd ,,} = \frac{2}{10} \text{ ,, ,,}$$

$$\text{,, ,, tie in 4th ,,} = \frac{1}{10} \text{ ,, ,,}$$

Similarly (*see* reciprocal diagram, Fig. 289),

$$\text{Compression in strut nearest abutment} = \frac{4}{10} \text{ of } S_s$$

$$\text{,, ,, ,, in 2nd panel} = \frac{3}{10} \text{ ,, ,,}$$

$$\text{,, ,, ,, ,, 3rd ,,} = \frac{2}{10} \text{ ,, ,,}$$

$$\text{,, ,, ,, ,, 4th ,,} = \frac{1}{10} \text{ ,, ,,}$$

In the example already considered the height of the columns was 80 feet, the distance apart 16 feet, and it may be assumed that there would be four equal panels as in Fig. 291.

The length of diagonals AC and BD is readily calculated. Then—

$$\text{Maximum vertical shear} = \frac{24}{10{,}000}\frac{L^2+D^2}{} \text{ tons} = 16{\cdot}57 \text{ tons.}$$

Resolving this in direction of struts we get—

$$\text{Total compression in struts} = 16{\cdot}57 \times \frac{16}{20} = 13{\cdot}24 \text{ tons.}$$

$$\text{Compression in bottom strut} = \frac{4}{10} \times 13{\cdot}24 = 5{\cdot}29 \text{ tons.}$$

Resolving 16·57 tons in direction of ties, we get—

$$\text{Total tension in ties} = 16{\cdot}57 \times \frac{25{\cdot}6}{20} = 21{\cdot}2 \text{ tons.}$$

$$\text{Tension in bottom ties} = \frac{4}{10} \times 21{\cdot}2 = 8{\cdot}5 \text{ tons.}$$

The above calculations give the maximum compressive and tensile stresses occurring in struts and ties, the members in the lowest panel being subjected to this loading. From previous statements it will be seen that the stresses in the individual struts and ties decrease towards the top of the framework; hence, theoretically, the section of these members may be reduced in proportion. In practice, however, it

is frequently the custom to allow for all struts to be of similar section, although in the case of the larger holders some reduction is admissible and conducive to economy. This particularly applies to holders having built up struts such as the lattice or open-box type. It must be borne in mind, however, that there is some tendency to deformation due to torsion, and this torsional force is a maximum at the top of the framing. Hence, too liberal a reduction in the section of the upper struts should not be permitted.

THE DESIGN OF STRUTS

Struts are best designed by trial and effect methods. That is to say, an engineer acquainted with the practical construction of holders will decide upon what he considers to be a reasonable section, and will then prove the stability of his section by ordinary theoretical methods. For this purpose the safe load which the strut is capable of withstanding may be calculated from the following modification of the " straight line " formula which the author suggests as being the most adaptable for the purpose :—

$$\text{Safe load} = 6\left(1 - \cdot0053\frac{L}{K}\right) \times \text{area of section.}$$

Where, L = length of strut in inches
K = *least* radius of gyration.

Then, the section must be such that the safe load given is not less than the compressive stress in the member calculated as shown above.

To return to the example in question, the maximum stress in the bottom strut is 5·29 tons. For a holder of this size the struts would be most economically composed of ordinary R.S.J. The probable section required would be 10″ by 5″ by 30 lbs. per foot. Applying the test formula to this, we get :—

$$\begin{aligned}\text{Safe load} &= 6\left(1 - \cdot0053\frac{L}{K}\right) \times \text{area} \\ &= 6\left(1 - \cdot0053 \times \frac{16 \times 12}{1\cdot05}\right) \times 8\cdot82 \\ &= 6\ (1 - \cdot9699) \times 8\cdot82 \\ &= 52\cdot92 \times \cdot0301 \\ &= 6\cdot76 \text{ tons.}\end{aligned}$$

The section is therefore amply strong for the purpose.

(*Note.*—The value of K for above may be readily obtained from one of the many sections tables published by the steel manufacturers, or it may be calculated from the principle that $K = \sqrt{\frac{I}{A}}$, where I is the *least* moment of inertia of the section.)

THE DESIGN OF TIES

The design of the tie-bars which, with few exceptions, consist of plain round mild steel rods is simple. If the load on the tie is known then the following formula gives the required diameter :—

$$\text{Diameter in inches} = \sqrt{\frac{\text{Load in tons}}{4\cdot71}}$$

In the example in question the maximum tension was found to be 8·5 tons, therefore—

$$\text{diameter of tie bar} = \sqrt{\frac{8{\cdot}5}{4{\cdot}71}}$$
$$= \sqrt{1{\cdot}8} = 1{\cdot}34 \text{ inches},$$

or, say, a $1\frac{3}{8}$ inch or $1\frac{1}{2}$ inch bar.

Round bars are to be preferred to other sections, such as flats, tees or channels, in that they are more simply connected to the standards and are more adaptable for tension gear. Care should be taken, however, to ensure that the rods are thickened at the screwed end, so that there is no loss in strength when the screw is cut. When connecting eyes are employed they must be of such design as to be of equal strength to the bar. The attachment of the eye to the standard should be such that the connecting pin is in double shear.

It will, of course, be understood that of the two diagonal ties in each panel only one is under stress at a time.

THE HOLDER BELL

In the design of the holder bell, particular consideration must be given to the top curb (where side sheets and top sheets meet), the ring curb at the base of the top lift, and the curbs at the upper and lower edges of succeeding lifts.

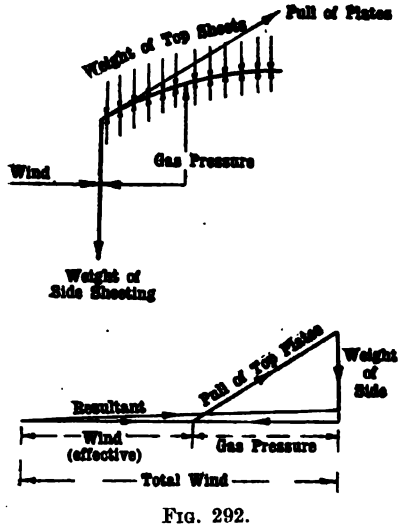


FIG. 292.

The top curb, owing to the gas pressure on the dome, is by far the most highly stressed. The forces acting on it are shown in Fig. 292. They produce, as is seen, a compound stressing which tends either—

(*a*) To tear the top bodily away at the junction of side and dome plates.

(*b*) To buckle the curb, side plates or dome plates.

The function of the top curb is, therefore, to resist these tendencies, whilst an additional safeguard is provided against the blowing-in of the side sheets by interposing vertical stiffeners at intervals around the cylinder. The resultant pressure of the gas on the interior of the dome, and the weight of the plates composing the dome, will be such as to produce a pull in the plates, the direction of which pull will be at a tangent to the point under consideration. So far as the plates forming the sides are concerned, the effect of the internal gas pressure is to produce a slight ring tension, but the plates are of necessity more than strong enough to cope with this. The ring stress is transmitted to the curbs by the vertical stiffeners, and in this way assists in counteracting the compression in the curbs. If buckling or distortion of the curb took place the ring tension would have

a tendency to right the whole to its circular form, but the effect would be almost inappreciable.

By a consideration of the main forces, it may be shown from the polygon of

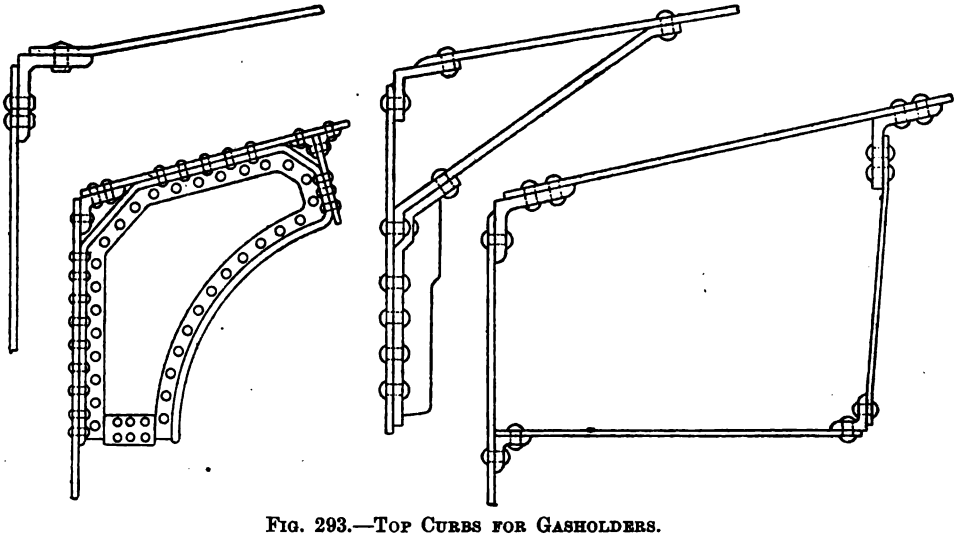


FIG. 293.—TOP CURBS FOR GASHOLDERS.

forces (Fig. 292) that the resultant acts in such a direction as to induce a compressive stress in the curb. The direction of the resultant will, in fact, be horizontal and in alignment with the direction of the wind. In the diagram of forces (Fig. 292) the

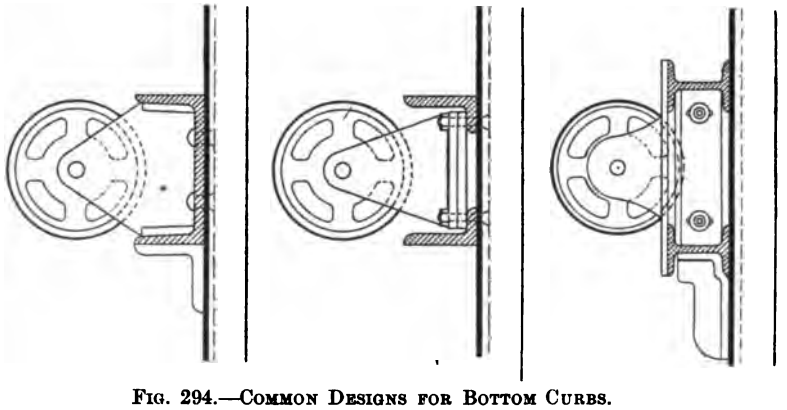


FIG. 294.—COMMON DESIGNS FOR BOTTOM CURBS.

resultant has been slightly tilted in order to show the conditions more clearly. Failure of the curb will be due, as may be seen, to an excessive compressive ring stress. In practice, however, the chief danger of buckling lies, not so much in the stresses produced by wind and top pull, but from the possibility of the bell tilting during its movement on the guide stanchions. In this direction a heavy drift of snow might give rise to danger.

For the purpose of withstanding any buckling effort which might occur, the dome curb in holders of any size should preferably be designed on the girder principle, or be provided with suitable gussets. Various forms of gasholder curbs are shown in Fig. 293. Cripps has pointed out that if these curbs are of sufficient strength to resist the compressive stress, then there will be little likelihood of buckling. Common designs for bottom curbs, that is the lower curb of the bottom lift, are shown in Fig. 294.

COMPRESSION IN THE TOP CURB

The compressive stress in the top curb and hence its necessary dimensions may be calculated as follows :—

Let D be the diameter of the top lift, in feet.

„ R „ „ rise „ „ dome, in feet.

„ P „ „ effective pressure thrown by the holder in lbs. per square foot.

As regards pressure it will be seen that if the total weight of the holder bell is W lbs., then the nominal pressure thrown would be $\frac{\text{W lbs}}{\text{area of bell}}$. It is necessary to consider, however, the upward pressure of the gas on the dome sheeting, which actually detracts from the total weight of the dome.

Thus, if $w =$ the weight of the top sheeting in lbs. per square foot,

and $h =$ the gross pressure thrown by the holder in lbs. per square foot,

then the effective pressure will be :—

$(h - w) \times$ area of bell $= \cdot 7854\ D^2\ (h - w) = P.$

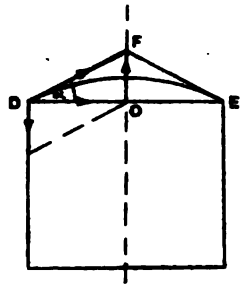


Fig. 295.

The net upward thrust on the dome due to the gas will then be equal to $\cdot 7854\ D^2\ (h - w)$, that is the effective pressure P. Then, referring to Fig. 295, it will be seen that the resultant vertical thrust is kept in equilibrium by the tangential pull at the circumference acting at an inclination DF or EF. In the triangle of forces FDO, if OF represents the net upward thrust of the gas, then DF represents in magnitude and direction the tangential pull in the plates.

$$OF = P$$

$$\text{and } DF = \frac{FO}{\sin. FDO} = \frac{FO}{\sin. a}$$

$$\text{Therefore, tangential pull, } T = \frac{P}{\sin. a} = \frac{\cdot 7854\ D^2(h - w)}{\sin. a}$$

$$\text{Or, T, per foot length of circumference} = \frac{\cdot 7854\ D^2(h - w)}{\sin. a} \times \frac{1}{\pi D}$$

$$\text{i.e. } T = \frac{D(h - w)}{4 \sin. a} \text{ per foot of circumference.}$$

$$\text{But } (h - w) = \text{effective pressure} = P \quad \therefore T = \frac{DP}{4 \sin. a}$$

This result is approximate, but any error is on the safe side. If the above expression gives the pull per foot of circumference then the total pull over the whole diameter—

$$= \frac{DP}{4 \sin. a} \times D$$

and this thrust is taken by the two sections of the curb diametrically opposite. Therefore, thrust on each section—

$$= \tfrac{1}{2}\left(\frac{DP}{4 \sin. a} \times D\right) = \frac{D^2P}{8 \sin. a}$$

Weight of the Side Sheets.

This may be calculated by taking out the weight of the side sheeting, curbs, guide rollers, etc., from the specification or, more readily, from a consideration of the above formula. The *effective* pressure thrown by the holder must necessarily be derived from the weight of the side sheeting, for owing to the upward thrust of the gas upon the dome the weight of this portion is ineffective. Considering Fig. 295, it will be seen, then, that the weight of the side sheets is represented by the vertical component of the tangential pull T; moreover, the resultant of the two forces T and W must be horizontal, otherwise the holder bell would not be in equilibrium, but would tend to be always moving upwards or downwards in its framing.

The resultant of T and W is, therefore, represented by the line DO (Fig. 295).

$$\therefore \text{ Resultant} = T \cos. a$$

$$= \frac{D^2P}{8 \sin. a} \times \cos. a = \frac{D^2P}{8} \times \text{cotan. } a$$

The angle a may be readily found as follows:—

$$\text{Cos. } a = \frac{D^2 - 4R^2}{D^2 + 4R^2}$$ where D = diameter of holder in feet,

and R = rise of dome in feet.

Internal Pressure of Gas on Sides

Cripps' method of calculating the effects of this force is to consider the ring tension in the side sheets, and to allow a definite proportion of this as transmitted to the curbs. Thus ring tension—

$$= \frac{h \times D \times d}{2}$$ where d = depth of lift in feet.

Then $\frac{1}{10}$ of the above is taken for holders having vertical stays attached throughout their length, and $\frac{1}{16}$ for stays attached at top and bottom only. The effect of the internal gas pressure is to counteract in some degree the external wind pressure and buckling effect. The extent to which this effect is felt is, at all events, an uncertain factor; and, in the light of practical observations, the author considers that it is quite reasonable to allow for it by deducting 55 per cent. from the usual figure taken for maximum wind pressure on a cylindrical surface; that is to say, to assume external effective wind pressure at 12 lbs. instead of 26 lbs. per square foot. This, of course, applies to those cases in which the vertical stays are attached throughout their length. Such an allowance would be representative of the effect in the majority

of holders now erected, and in the case of the very large holders any slight error would be on the right side.

Objection might be raised to this method owing to the fact that the gas pressure, the magnitude of which is easily computed, is taken as constant in all holders. But as the whole treatment must necessarily be one of some conjecture the author considers that his assumption, owing to its simplification of formulae, is perfectly justifiable.

Effective wind pressure, therefore,

$$= D \times d \times 12 \text{ lbs. per square foot.}$$

But this is distributed to both upper and lower curbs of the lift and is also withstood by the two diametrically opposite sections of the curb. Accordingly, the total force on any section of the curb,

$$= \frac{1}{4} \times D \times d \times 12 = 3\,Dd.$$

By a summation of the above force and the resultant of the tangential and vertical pulls, which act parallel with the wind, the total compressive force on the curb may be readily calculated.

COMPRESSIVE FORCE IN TOP CURB

$$= \frac{D^2 P \operatorname{cotan} a}{8} + 3\,Dd.$$

Where D = Diameter of holder in feet.

P = Effective pressure in lbs. per square foot.

a = Angle made by tangent with chord at base of the dome or, the angle a may be found from the following. (Note the formulae gives cos. a and not cotan. a direct.)

$$\text{Cos. } a = \frac{D^2 - 4R^2}{D^2 + 4R^2}$$ where R = rise of dome in feet.

d = Depth of top lift in feet.

In the event of the holder being designed with vertical stays attached at top and bottom only, substitute $5Dd$ for the expression $3Dd$ above.

Having obtained the total compressive force it is merely necessary to design a curb of sufficient cross-sectional area to safely withstand this. A stress of 6 tons per square inch should not be exceeded. In calculating the cross-sectional area it should be remembered that the two outer crown rows and the two top side rows of the sheeting may be included in the effective area. These plates should be butted, when the full cross-sectional area may be considered effective, but if lapped the shearing strength of the rivets only should be considered.

CUPS AND GRIPS

The proportions of cups and grips for telescopic holders have already been dealt with (page 426). There are two standard types, namely the semi-circular cup and grip as seen in Fig. 296, and that composed of the square channel section (Fig. 297). The channel type is strongly to be preferred. It is simply constructed, while it

obviates the objectionable initial stressing which is set up in the semi-circular grip when the plate is bent to shape. Moreover, if one portion is not in perfect alignment with its counterpart, a grinding action will be set up when the two come together. This will be particularly severe when there is some slight constructional defect, such as the grip being slightly larger than the cup, or if the two are not set to an exact circle. If the grip is slightly large the cup will not engage centrally, with the result that the grip is slightly tilted and the guide rollers are, in turn, thrust hard over against the columns. The effect will be noticed by a consideration of Fig. 298. The tendency can, of course, be minimized by additional guide rollers on the grip running on guides attached to the inner lift.

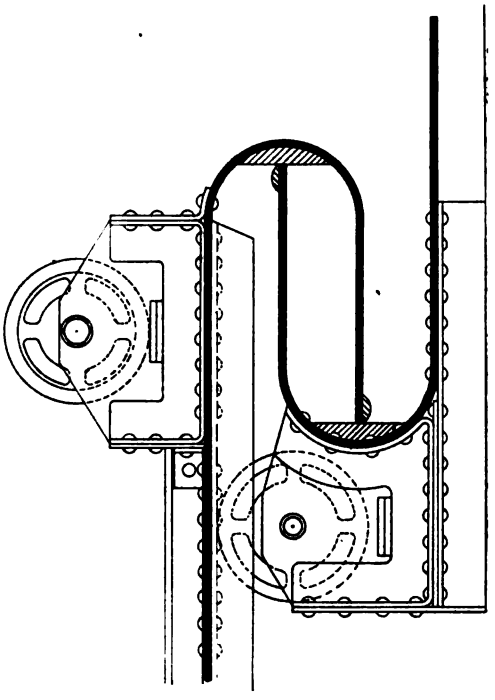


FIG. 296.—SEMI-CIRCULAR CUP AND GRIP.

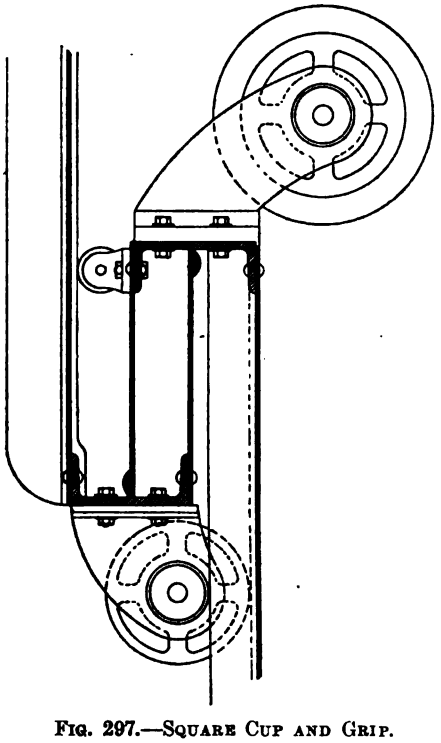


FIG. 297.—SQUARE CUP AND GRIP.

When properly constructed, the grip with the weight it carries should act as a steadiment to the inner lift, and counteract any tendency towards tilting.

When designing the cup and grip, sufficient width should be allowed so that riveting may be carried out with ease. The minimum width should be 8 inches. The cup sides and cup rows on the bell must be stouter than the normal side sheeting, and a beading, to increase rigidity, should be run all round at the base of the cup side. The stouter cup sheets will prove effective in meeting any corrosion due to the changing level of the water in the lute. In addition, they avoid the undesirable practice of riveting very thin sheets to the thick section of the cup or curb. The thickening up of these plates enables the reduction to be effected in two steps. For the cup rows and cup sides $\frac{1}{4}$ inch sheeting

is common, while the beading, which may be either moulded or flat, varies from $\frac{5}{8}$ inch to $\frac{3}{4}$ inch thick; but everything, of course, depends upon the size of the holder.

The crown sheeting of gasholders varies from 14 gauge to 10 gauge in thickness (i.e. $\frac{5}{64}$ inch to $\frac{1}{8}$ inch), depending entirely upon the size of the holder; curb rows being, of course, thicker ($\frac{1}{4}$ inch to $\frac{3}{8}$ inch in medium sized holders, and so much as $\frac{7}{8}$ inch in large holders). As regards side sheeting, this varies from 12 gauge to 10 gauge in thickness; curb, or cup and grip rows again being heavier. The side sheets of the top lift are occasionally thicker (say 8 gauge) than those of succeeding lifts; and it should be remembered that where joints between rolled sections and plates occur it is always advisable to use heavier plates, so as to avoid attaching a very thin section to a thick one, a practice generally followed by imperfect and leaky joints. The sheets employed should be as large as practicable, for the jointing is then reduced to a minimum and the labour of riveting is lessened. On the other hand, smaller plates and, therefore, more liberal riveting have a tendency to stiffen up the whole shell.

FIG. 298.

The thinner sheets of the gasholder bell are usually riveted up cold with $\frac{1}{4}$ inch rivets at a pitch of 1 inch, or $\frac{5}{16}$ inch rivets at $1\frac{1}{8}$ inch pitch. Curb and such rows have stiffer rivets at a slightly greater pitch, but all rivets above $\frac{1}{2}$ inch diameter must be driven hot. For the purpose of making the joints between the plates gastight, it is essential to insert at the lap strips of tape soaked in red lead.

SUPPORT FOR THE CROWN

The dome of a gasholder, owing to its frail construction, requires some form of support when the holder is grounded and is receiving no support from the internal pressure of the gas. There are two common methods of preventing the crown from buckling inwards, namely:—

(*a*) The provision of an internal trussing to the crown, on the lines of the framing of an umbrella.

(*b*) The erection of a crown rest in the tank.

In the former method the framing is affixed to a series of rafters radiating from the centre and attached to the crown curb. A strong centre column is also provided, and when the holder is grounded this rests on a bed-plate or pier in the centre of the tank (Fig. 299). For smaller holders the crown trussing is generally employed, and Cripps says that it would be unwise to abolish the system in the case of the smaller crowns, for, owing to its lightness, it would be impossible to put anything cheaper into the tank in the form of separate frames. The amount of metal, and consequently the cost, increases rapidly as the holder becomes larger, so that it may be

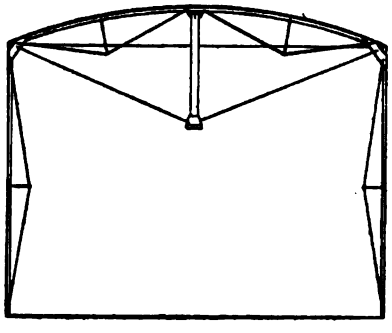


FIG. 299.—CROWN TRUSSING FOR HOLDER.

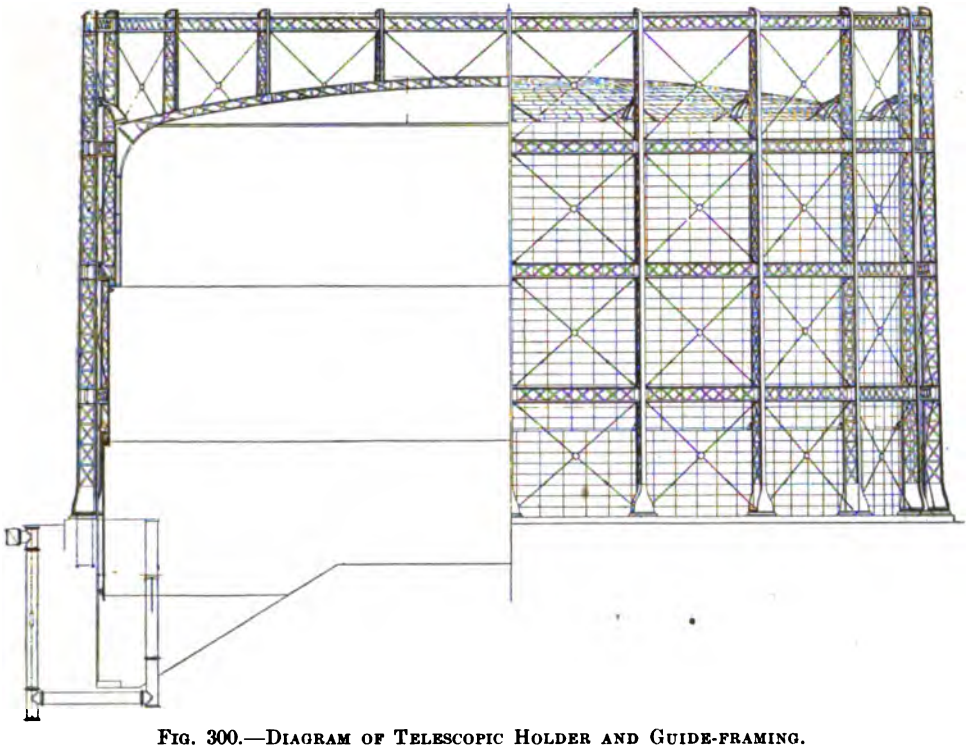


FIG. 300.—DIAGRAM OF TELESCOPIC HOLDER AND GUIDE-FRAMING.

said that the trussed crown must be limited to holders not having a greater diameter than about 170 feet. The weight of the trussing in large holders would tend to distort the spherical shape of the crown, which the upward gas pressure is assisting. The internal framing should be as independent of the crown sheeting as possible in order to prevent the possibility of straining the seams.

As regards the crown rest this consists of a series of radiating rafters carried on columns erected in the tank and connected together

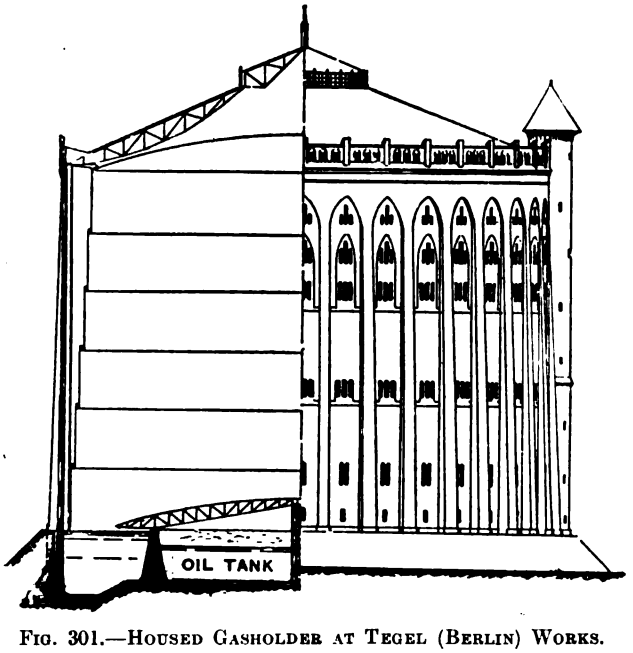


FIG. 301.—HOUSED GASHOLDER AT TEGEL (BERLIN) WORKS.

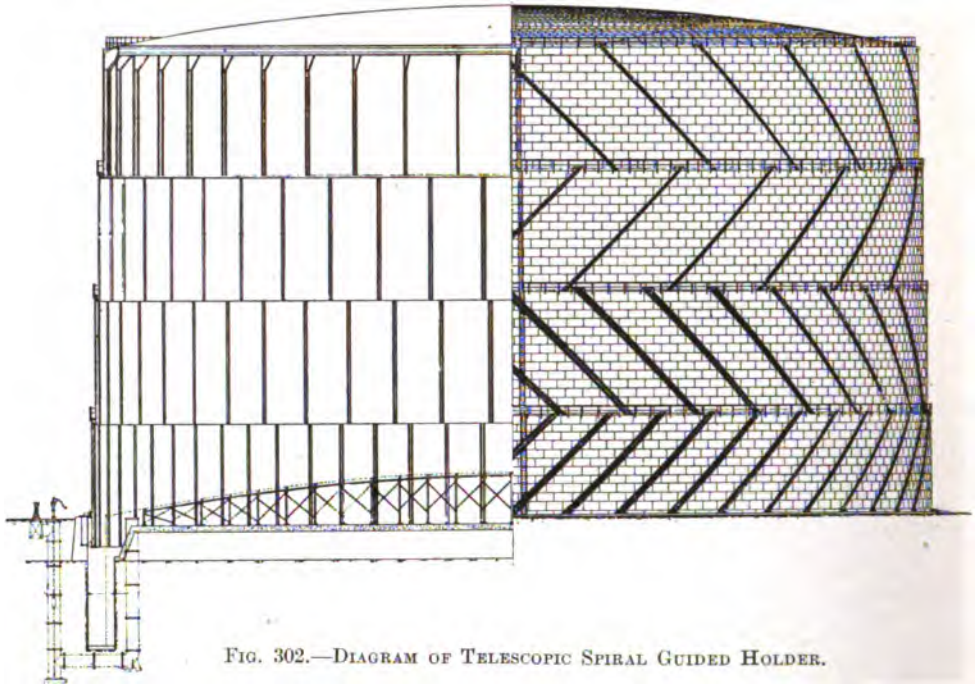


FIG. 302.—DIAGRAM OF TELESCOPIC SPIRAL GUIDED HOLDER.

by purlins to form a skeleton framework of the same camber as the dome. The frame is frequently constructed from timber, although light sections of rolled steel may be economically employed. The design is simple and may be seen in Figs. 287 and 302. An important consideration is that of arranging for the bracing of the columns, which are usually of some considerable height, particularly in the cases of the flat-bottomed steel tanks.

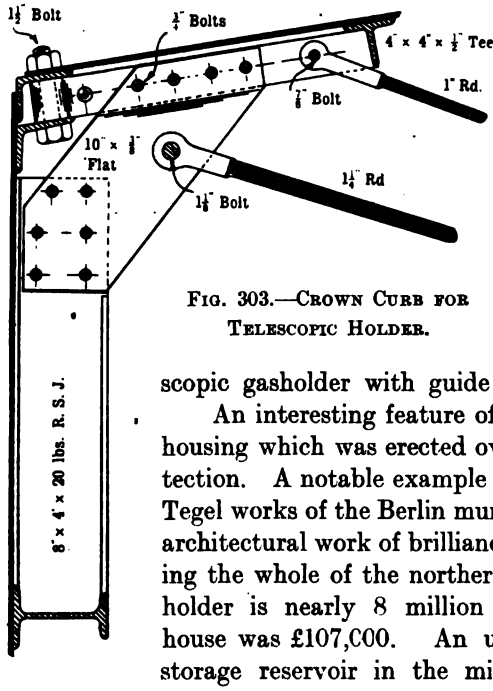


FIG. 303.—CROWN CURB FOR TELESCOPIC HOLDER.

A complete diagram of a telescopic gasholder with guide framing is given in Fig. 300.

An interesting feature of some of the earlier gasholders was the housing which was erected over and around them as a means of protection. A notable example of the covered gasholder is that at the Tegel works of the Berlin municipality (Fig. 301). The building is an architectural work of brilliance, being 300 feet in height and overlooking the whole of the northern part of the city. The capacity of the holder is nearly 8 million cubic feet, and the cost complete with house was £107,000. An unusual feature is the lead-covered oil storage reservoir in the middle of the tank.

SPIRALLY GUIDED GASHOLDERS

The spirally guided gasholder, the proposal of Mr. W. H. Y. Webber and the invention of Mr. W. Gadd (Fig. 282, p. 423) with which an external guide-framing is wholly unnecessary, was first installed in this country in 1888. At the time of its introduction there was much discussion as to the stability of the design, and many engineers pronounced the system as dangerous. As holders of the kind have now been in operation for upwards of twenty-five years, there can be little doubt that with proper precaution in design and supervision during working they are no more likely to fail than the guided types, whilst with modern improvements there is practically no limit, within reason, to the dimensions to

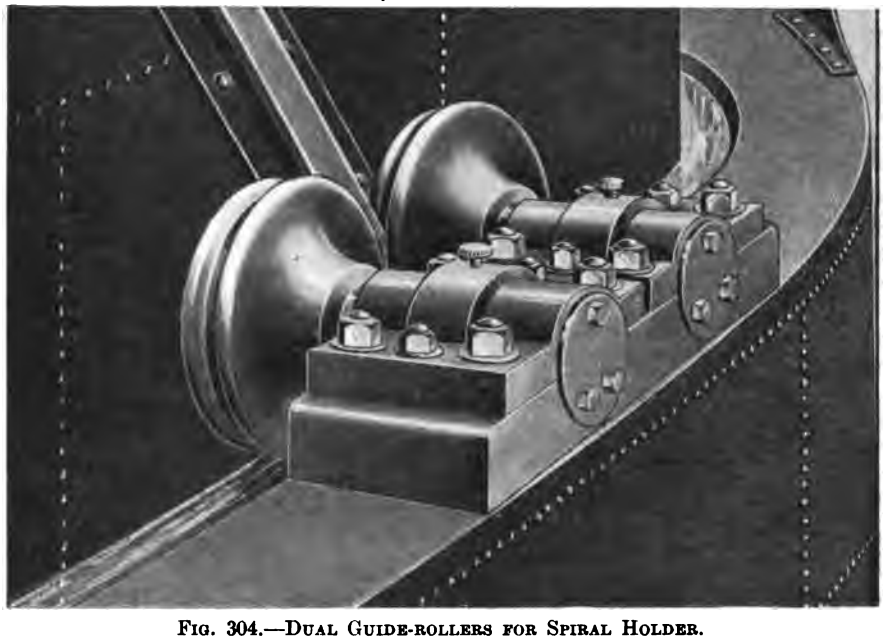


FIG. 304.—DUAL GUIDE-ROLLERS FOR SPIRAL HOLDER.

which they may be constructed. Briefly, the principle of their operation is dependent upon the introduction of spiral guide rails affixed to the holder side, these acting in lieu of the vertical standards and bracing of the more common type of holder. The spiral rails engage with rollers on the edge of the tank in such a manner that the bell screws itself up and down. The direction of the spiral may be either left-handed or right-handed, or successive lifts may operate in reverse directions as shown in Fig. 302. The rails on the outer lift must be affixed to the exterior of the bell, but those on succeeding lifts may be either interior or exterior, although the latter are invariably employed. The holder seen in Fig. 302 is of the four-lift spiral type, operating in an annular brick tank. The crown is untrussed, being supported, when the bell is grounded, by a timber framing. It will be noticed that to the two lower lifts are attached twin spiral rails, which

are desirable in all spiral holders of 250 feet diameter and upwards. (As the effect of frost might be attended by serious results, it is frequently the custom to instal an anti-freezing apparatus in connection with the water-lutes of modern holders.) It will be seen that it is the guide rollers which have to withstand the ordinary forces acting on the bell, and, through them, the forces are transmitted to the upper tank curb. The curb has, accordingly, to be of particularly stout construction, the more so if provision is made in the original structure for the insertion of an additional (outer) lift at some later date, in which case the tank rollers will have a considerable overhang.

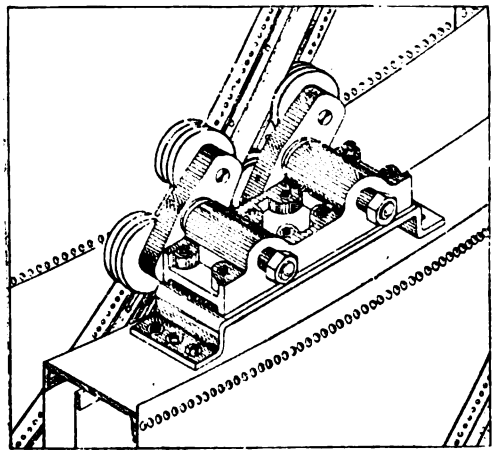


FIG. 305.—MULTIPLE ROLLER CARRIAGE FOR SPIRAL HOLDER.

Per unit of capacity the spiral holder is considerably cheaper than the guide framed type. It requires, however, great accuracy of fitting; and, when composd of a number of lifts, an element of danger from "jamming" or breakage is introduced by the numerous sliding brackets and rollers. Trouble might chiefly be expected in countries in which marked variations of temperature are met with, for the bell is subject to a certain amount of radial contraction and expansion. This difficulty has been overcome by the introduction of special compensating carriages. The bell of the spiral holder is of much stiffer construction than that of the ordinary holder, and some form of trussing is usually employed in the crown. A suitable form of crown curb for a holder of about 125 feet diameter working on this principle is seen in Fig. 303.

FIG. 306.—MULTIPLE ROLLER CARRIAGE.

The guide rollers are either of the dual or multiple type. The dual type illustrated in Fig. 304 are provided with continuous automatic lubrication, being so designed that the axle runs in a bath of oil formed in the bedplate of the carriage. The multiple roller carriage, in which four instead of two rollers are employed, is shown in Figs. 305 and 306. It will be observed that the bolts securing the carriage are brought as near as possible to their work, thus reducing the strain from leverage upon the tank and the carriage. As regards pro-

vision for any radial contraction or expansion of the bell, this is usually arranged for by fitting a sliding axle as in Fig. 307. The oil grooves in the axle, and the special packing rings at front and back to prevent the lubrication from being lost, will also be noticed. The roller is not free to revolve on the axle, but fixed to it. The space for expansion is shown between the back of the roller and the front of the carriage. A recent feature is the "run down stop" which is affixed at the upperends of the guide rails. At the inquiry held in connexion with the gasholder accident at Ilkeston it was suggested that the outer lift "jammed" and the inner lift ran through and fell into the tank, the concussion thereby causing fracture of the latter. The "run down stop" prevents such an occurrence, and may be readily fitted to existing gasholders. In Fig. 308 is shown the method of holding down the roller carriage to the upper edge of a brick tank. The

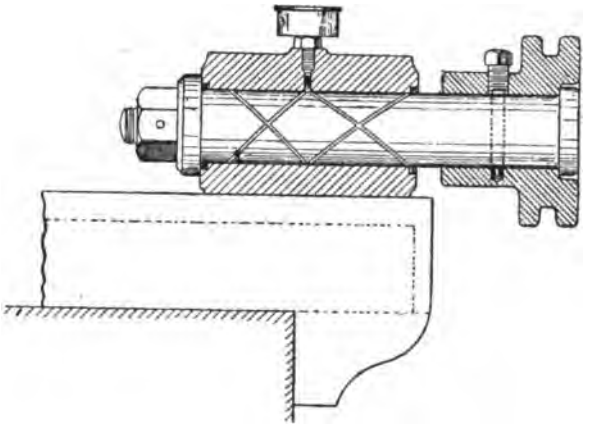


FIG. 307.—SLIDING AXLE FOR ROLLER.

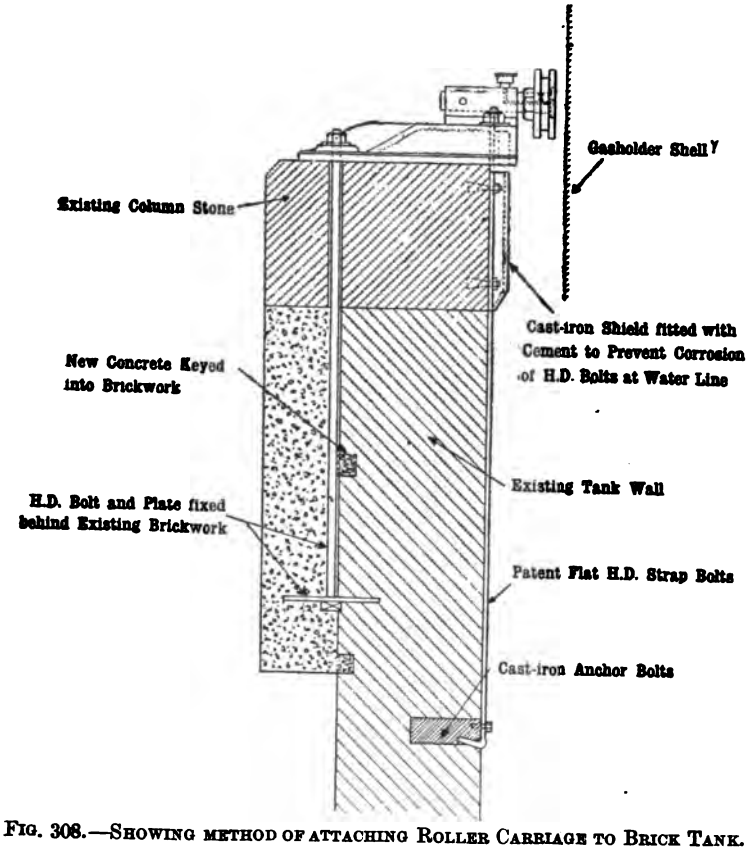

Gasholder Shell
Existing Column Stone
Cast-iron Shield fitted with Cement to Prevent Corrosion of H.D. Bolts at Water Line
New Concrete Keyed into Brickwork
Existing Tank Wall
H.D. Bolt and Plate fixed behind Existing Brickwork
Patent Flat H.D. Strap Bolts
Cast-iron Anchor Bolts

FIG. 308.—SHOWING METHOD OF ATTACHING ROLLER CARRIAGE TO BRICK TANK.

method shown is particularly applicable when a tank formerly constructed to take a bell guided by standards is adapted for the use of a spiral holder.

THE NUREMBERG HOLDER

So far as originality is concerned, the new " floating roof " holder (hailing from Nuremberg) demands a certain amount of attention. The principle employed permits of the expensive water tank being dispensed with altogether, although " gas-

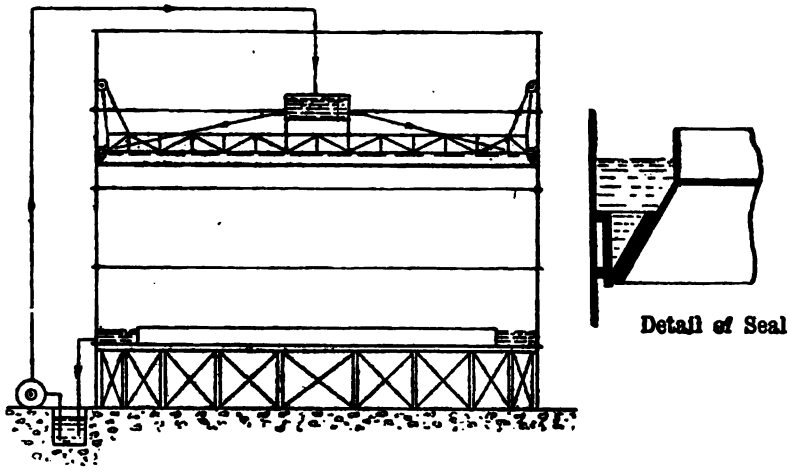


FIG. 309.—THE NUREMBERG HOLDER.

tightness " is ensured by the use of a water seal as heretofore. Simply explained, the holder (Fig. 309) consists of an outer cylindrical shell very similar in appearance to the present holder bell, but with the exception that the roof is the only moving portion. The contrivance is, in fact, little more than a cylindrical tank, the roof of which is, by means of guide rollers, permitted to rise or fall within the tank. Gas in the ordinary way is admitted beneath the roof, which ascends and descends in accordance with the prevailing pressure in the interior. The guidance of the floating roof is such that the smallest amount of clearance is permitted between it and the internal periphery of the cylinder. The means employed for the prevention of gas leakage consists in pumping water upon the exterior of the roof so that it runs down to the portions above the guide rollers and seals up the clearance between cylinder and dome. Some portion of the water is, of course, continually passing through this clearance into the interior of the holder, whence it is removed by way of a seal and returned to the suction of the pump.

THE LIVESEY MAN-LID

The man-lid introduced by the late Sir George Livesey is a convenient device commonly fitted to holders for facilitating inspection of the gas inlet and outlet pipes.

In the ordinary way, if a simple manhole cover was employed the gas between the water level and the crown would be lost. The man-lid, however, prevents this. It consists (Fig. 310) of a circular hood bolted to the underside of the gas-holder crown. To the side of the hood is attached a seal tank with a feather plate projecting halfway down into it. There is an aperture in the hood, near the crown, to allow the gas in the hood to escape when the holder is coming down on to the rest stones. When the bell is at rest the seal tank is filled with water until the seal on the hanging plate is greater than the pressure in the holder. The man-lid may then be removed.

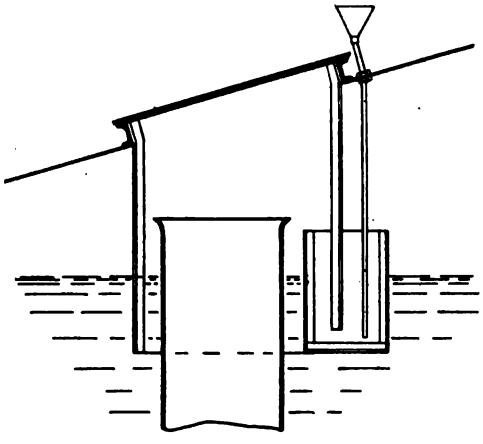


FIG. 310.—THE LIVESEY MAN-LID.

GASHOLDER TANKS

Gasholder tanks as now erected may primarily be classified under three headings :—

(*a*) Buried tanks, the top of which is approximately level with the prevailing ground line.

(*b*) Tanks entirely aboveground, in which the top of the concrete foundation is on a level with the ground line.

(*c*) Semi-buried tanks which are constructed partly below ground and which are "banked up" level with their upper edge with the material taken from the excavation.

There is, in addition, a fourth, but uncommon, type, in which the floor of the tank is constructed upon piers or arches above ground level, the space below being employed as a storehouse or for some similar purpose. With one or two possible exceptions, it may be stated that types (*a*) and (*c*) are almost solely constructed from brick, concrete or reinforced concrete, while steel, reinforced concrete, or cast iron are employed in all tanks aboveground. From the point of view of modern practice, cast iron may be dismissed from consideration forthwith. It was employed largely some three or four decades ago at a time when rolled steel plates were extremely costly and could not be obtained of sufficient thickness for large tanks. The number of brick tanks which are to be found to-day, particularly in connexion with the older gasholders, is chiefly the outcome of the fact that in years past it was not deemed advisable to construct cast-iron tanks above a certain capacity; and, as the cost of steel was still prohibitive, the only alternative was that of excavating a hole and lining it with a shell capable of retaining water and of sufficient stability to withstand the forces acting against it.

Brickwork and Concrete Tanks

Tanks composed of brickwork are, in general, of two descriptions :—

(*a*) Puddled tanks.

(*b*) Rendered tanks.

The main difference between the two types is in the means introduced for ensuring that the tank shall be water-tight. Brickwork, *per se*, is not impervious to water, hence recourse must be had to some means of making it so. Water-tightness is ensured either by jacketing the tank on its exterior surface with a layer of puddled clay (hence the expression " puddled tank "), or by coating the interior of the tank

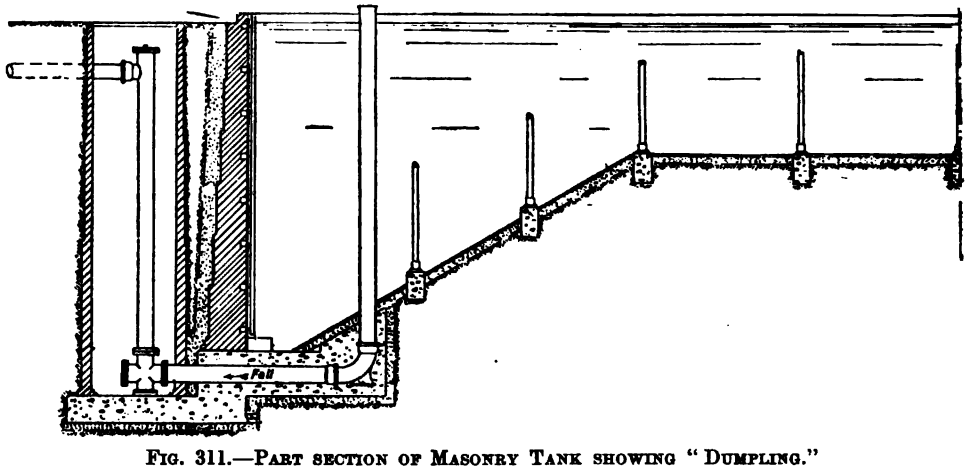


Fig. 311.—Part section of Masonry Tank showing " Dumpling."

with a thin rendering (about ½ inch to 1 inch thick) of neat cement or rich mortar, in which case it will be a " rendered tank." A half section of a typical puddled tank, showing how the work of excavation is lessened by leaving a " dumpling," is shown in Fig. 311. In constructing a tank of this description, it is usual to build up the brickwork in short lifts and then to fill in with puddle between the wall and the ground. The puddle may consist of pure clay, but some engineers at one time preferred to introduce a small proportion of sand or mould in order to prevent cracking when the material dries off. As each layer of puddle is filled in it must be well moistened and thoroughly " punned." It will be noticed from the accompanying figure that the puddle is spread entirely over the " dumpling."

An elementary consideration of the static pressure of water is sufficient to show that the bursting pressure at any section due to the contained water varies in direct ratio to the depth of the section below the surface. Thus for determining the pressure due to water at any point the following simple formula may be used :—

$$P = w\,d$$

where P = pressure in lbs. per square foot

w = weight of a cubic foot of water

d = depth below surface in feet.

In a circular tank the radial thrust will, therefore, gradually increase from the surface of the water to the bottom of the tank; in other words, the magnitude of the pressure is shown by the line AB (Fig. 312) and the thickness of the tank wall may theoretically be graduated in accordance with this line. Theoretically, no thickness at all is required at the surface of the water, but for reasons too obvious to need explanation such a condition is impossible in practice.

From a consideration of the simple formula previously given, it might be presumed that the calculation of the stresses in a masonry tank, and hence its design, would be a comparatively easy operation. Such, however, is by no means the case, for many factors of an uncertain nature (such as the cohesive resistance of the brickwork) are introduced, with the result that a purely theoretical method of design is extremely difficult of application. There is no doubt that in the design of a masonry tank some sound theoretical treatment would prove of immense value, but at present there is no such treatment at our disposal, with the result that practical experience and the lesson of precedents chiefly influence the designer. Herein lies one of the paramount advantages of the steel tank, our knowledge of which permits of a reasonably accurate computation of the stresses to which it will be subjected. Occasionally one may come across the most elaborate calculations for arriving at the factor of safety obtaining in a masonry tank worked out to two decimal places. The inconsistency of such procedure should be self-evident when it is remembered that the theories so far laid down for the treatment of these tanks are merely the result of surmise, and are built up from a series of pure structural considerations, which probably have no relation to actual conditions.

Some forty years ago a series of formulae were deduced wherewith it was proposed to calculate the stability of masonry tanks. These formulae are still in use at the present day, and may be found quoted in modern text books. A cursory examination of the formulae, however, would appear to show that they contain such elementary errors as that of assuming the horizontal pressure of earth constant for all depths and independent of the distance below the surface. Any one acquainted with the theories of Rankine and others will perceive the absurdity of such an assumption. It must be realized that the brick tank of a gasholder is not subjected to a simple bending moment as in the case of an ordinary retaining wall, but stresses are set up on the lines of those occurring in the plates of a cylindrical boiler, and instead of the wall tending to tilt over from the base the whole undergoes, in almost all cases, slight circumferential stretching, whilst there is also a strain in the vertical direction. As in the case of the steel tank, which receives support from the bottom curb and floor space, so is the brick wall restrained to a certain extent by its adhesion to the foundations.

H. W. Alrich, in a communication to the American Gas Institute, has shown that the restraint exercised by the foundation will reach, approximately, a distance up from the bottom of the tank equal to $\frac{1}{5}$ to $\frac{1}{4}$ of the total depth of the tank. Accordingly, if in the diagram (Fig. 312) the dotted line represents the tank as constructed, the position and shape it will take up when filled with water will be of the nature of that shown by the full line. As before explained, the theoretical thickness at the

top is nil, but the thickness allowed in practice is such as to prevent a certain amount of stretching in the upper portion; thus there is in reality a restraining influence at both top and bottom.

The author has made a particular study of the various mathematical treatments which have been suggested for the computation of the stresses induced in masonry tanks, but finds that on examination they are more likely to be misleading rather than of any service in design. It is believed that hitherto the vertical strain in the tank, an extremely important factor in the evolution of a theoretical treatment, has never been considered, and there is no doubt that the difficulty of ascertaining this with accuracy is not encouraging.

The nature of the assistance of the earth backing has given rise to a good deal of controversy, some authorities believing it to be active, and some passive. There can be little doubt, however, that once the tank has been put under stress the ring tension and circumferential stretching induced are followed by a passive resistance in the earth. The earth, moreover, is a somewhat uncertain quantity. To emphasize this it is only necessary to refer to the well known work of Sir Benjamin Baker. In the course of his examination of dams and river walls, Baker found that in some cases it was possible to thrust down an iron bar some considerable distance between the earth and the brickwork, showing that the latter was receiving practically no assistance from the earth backing. Such conditions might well be found in the case of semi-buried tanks having the earth mounded up against the upper portion. In such instances there may be some tendency for the earth to slide backwards and so relieve the pressure against the wall.

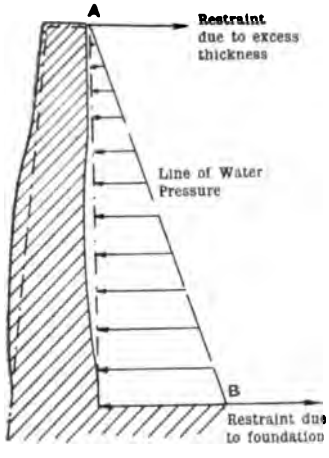


FIG. 312.—SHOWING EFFECT OF WATER PRESSURE ON MASONRY TANK.

An old-fashioned rule, due to Wyatt, for the proportion of brick tanks, is as follows:—

Thickness of concrete walls = $\frac{1}{10}$ the depth of tank
,, ,, piers = $\frac{1}{5}$,, ,, ,, ,,
Width ,, piers = $\frac{1}{7}$,, ,, ,, ,,

This refers to tanks up to 150 feet diameter and 36 feet deep.

For very large holders, a brick or concrete tank is most suitable, so long as a firm foundation, free from water, can be obtained. Concrete tanks, with cement and ballast at reasonable prices, are cheaper than the brick variety, and they are in almost all cases rendered on the interior. The brick tank possesses advantages over the concrete tank in that less skill is required in its construction, there is less initial stress due to shrinkage, and less liability towards cracking caused by any variation in the temperature of the water. The method of connecting up inlet and outlet pipe to a gasholder with masonry tank and the construction of the "dry well" is shown in Fig. 311.

Steel Tanks

It may be laid down as a general rule that unless a gasholder is upwards of two million cubic feet capacity a steel tank is undoubtedly the most economical. In modern practice the steel tank finds considerable favour in all cases except where the holder is of considerable size, although steel was employed for the New York holder tank, which has a diameter of 250 feet and a depth of 46 feet. The capacity of this holder is ten million cubic feet.

Steel tanks may be said to possess the following advantages :—

(*a*) They are usually less expensive than masonry tanks.

(*b*) A foundation which might be classed as unsuitable for a sunk tank may be sufficiently stable for a steel tank.

(*c*) Quickness and ease of construction.

(*d*) Owing to the ease of determining the working stresses with reasonable accuracy there is no difficulty in designing the tank with a known factor of safety.

(*e*) Steel is reliable under stress. The properties of brickwork and concrete in this direction are uncertain.

(*f*) The tank can be readily tested and made water-tight, for the whole is accessible for inspection. As regards the floor plating, it is usual to put the sections together on bearers which raise it a short distance above the foundation. When the floor, bottom curb and bottom row are riveted up, the tank is filled with water to a depth of about one foot. Any joint " weeps " are then attended to and the whole is afterwards let down on to its foundation.

(*g*) Masonry tanks must be allowed to stand for some time after completion before they are filled with water. The steel tank may be filled immediately it is finished.

(*h*) With the steel tank there is no initial stressing caused by shrinkage or change of temperature.

(*i*) The failure of a steel tank is extremely rare.

On the other hand, the advocates of the masonry tank point out that :—

(*a*) The life of a steel tank is short in comparison with that of the masonry tank.

(*b*) The exterior of a steel tank is affected by corrosion, thus fairly frequent painting is essential. This periodical expense is not incurred with the buried tank. (It should be noted, in this connection, that the inside surface of the plates, being always under water, is not affected by corrosion, except to a certain extent at and above the surface of the water.)

(*c*) The crown-rest framing for the holder bell will be more costly, owing to the impracticability of employing a dumpling.

(*d*) The guide standards of the holder will be longer.

The Design of Tanks

When the erection of a gasholder is contemplated, trial holes must be bored down on the site in order to determine the suitability of the ground for foundations. A good foundation is absolutely essential, not only to provide for the satisfactory

working of the holder, but to ensure economy in construction. Where brick tanks have been already built, care should be taken that the ground in their vicinity is not violently disturbed. Instances can be pointed to where such tanks have been cracked by the driving of piles near by. Good ballast may occasionally be obtained from the subsoil, and in this case it may prove more economical to provide a concrete tank, even though the holder be comparatively small.

As regards the foundations for steel tanks, the circular slab is usually levelled off flush all over, but some designers prefer that the concrete should slope up to a height at the centre of 4 or 5 inches above the level at the periphery. It is said that in this manner, if there is any sinking of the ground underneath, the bottom will assume a level bedding. It would seem, however, that if any rise is to be given this should be allowed at the periphery (where the whole of the weight of side sheets and standards is concentrated) rather than at the centre. As in the case of the masonry tank, the gas inlet and outlet pipes are led up through the floor of the steel, tank, but they should be constructed from wrought iron and with the open ends bell-mouthed. The floor plates themselves are comparatively thin and should be rectangular, except for those in the outer row, which are made to the circular shape of the tank and are usually slightly thicker. Outside floor plates are usually $\frac{5}{16}$ inch to $\frac{3}{8}$ inch, with the curb row $\frac{1}{2}$ inch thick.

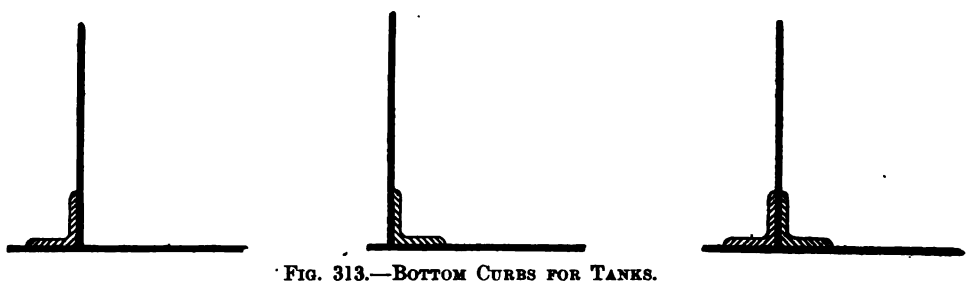


FIG. 313.—BOTTOM CURBS FOR TANKS.

The bottom row of the side sheeting is composed of the heaviest plates in the structure, the thickness of the plate depending upon the depth of the tank, but in exceptional cases being as much as $2\frac{1}{4}$ inches. These plates are connected to the tank floor by means of a bottom curb which usually consists of a single angle placed internally or externally, or of a double angle, as shown in Fig. 313. By far the most common practice, however, is to provide the internal angle alone. In the treatment of gasholder tanks it is generally assumed that a certain amount of restraint is exercised by the bottom curb and floor plates in preventing the circumferential stretching of the bottom row when the tank is under load. This, no doubt, is the case, but a series of experiments carried out with scale models at one of the London colleges has shown that the magnitude of this restraint is actually very small.

In designing tanks for gasholders it is usual to calculate the required thickness of the side plate by considering the head of water as equal to the depth above the centre of gravity of the plate, and not the depth to the base of the plate. The author is of the opinion that such a practice is inadvisable and that the depth to

the base of each row should be taken when the stability of that row is being calculated.

When arriving at the thickness of the bottom row of side plates, some allowance is often made by designers for the restraint due to the floor plating. The most ready means of doing this is to make a deduction from the total depth of the tank. This deduction usually amounts to about 3 per cent of the depth. It should be borne in mind, however, that owing to the restraining influence of the bottom curb, however slight this may be, the bottom row plates will be prevented to a certain extent from joining in the expansion of the remainder of the ring. Accordingly, bending stresses will be set up in the lowest ring plates, for which due allowance should be made.

So far as the author is aware the largest steel tank erected is that at the Kings-

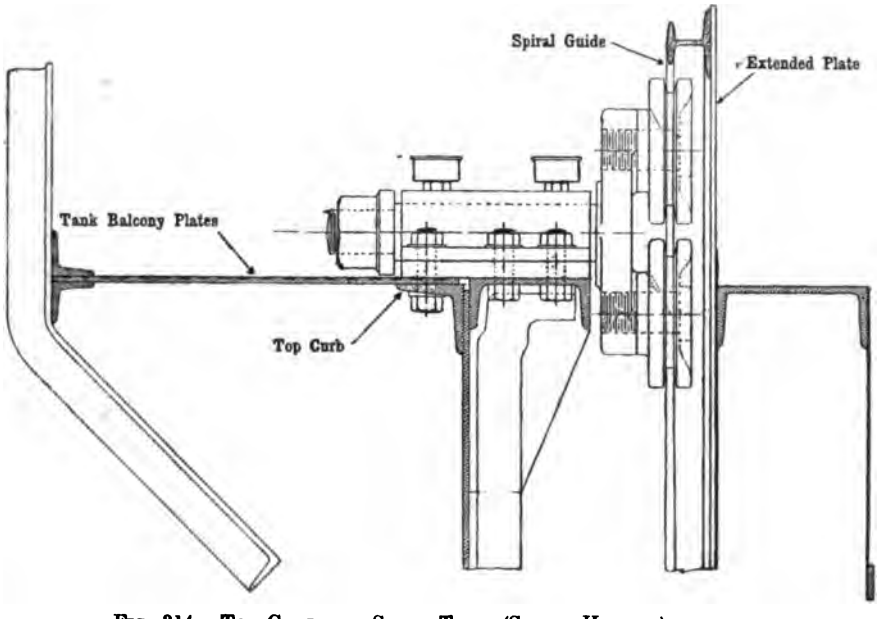


FIG. 314.—TOP CURB FOR STEEL TANK (SPIRAL HOLDER).

bridge works of the New York Consolidated Gas Company. The holder has a capacity of 10 million cubic feet, whilst the diameter of the tank is 251 feet 3 inches, with a depth of 46 feet 4 inches. The tank shell is composed of nine rows of plates, the lowest row of which is $2\frac{5}{16}$ inches thick, the plates being 4 feet in height. The topmost ring consists of $\frac{1}{2}$ inch plates, 6 feet in height. All the vertical seams—and here it should be pointed out that in the riveting of tanks it is the vertical seams which require particular forethought, the horizontal joints give little trouble—are double butt-joints designed so that a portion of the rivets are acting in single shear and some in double shear, and so arranged that the efficiency of the joint is 93 per cent. All the horizontal seams are lap joints single-riveted with rivets varying in

size from 1¾ inch at the base to 1 inch for the top row. Both plates and butt-straps are bevelled-edged, this or ordinary planing being commonly carried out to facilitate caulking. The tank bottom is formed of ⅜ inch plates, 20 feet long, and 7 feet 6 inches wide, connected together by ⅝ inch rivets. The curb row of plates is ⅝ inch thick. The bottom curb consists of an external angle, 8 inches by 8 inches by 1⅛ inch thick, put together in twenty-six sections joined by angle connexion plates. The upper curb of the tank consists of a horizontal plate ½ inch thick attached to the tank shell by a 5 inch by 5 inch by ½ inch angle, and is stiffened round its outer edge by a 12 inch channel.

A point of importance in the design of holders with steel tanks is that of ensuring that the tank structure shall itself be as independent as possible of the stresses set up in the guide framing. Any such stresses should be carried down, not to the top curb of the tank, but to the foundation. This precept is often overlooked, with the result that the tank plates are subjected to stresses for which they were not designed. A frequent error in design is that of carrying the diagonal cross-bracing of the panel down to the top curb of the tank, thus leaving the tank-panels unbraced. As regards the guiding of the bell in the tank it is customary to provide intermediate rails between those fixed at the main upright stanchions. The construction of the top curb for a steel tank to take a spirally guided bell is shown in Fig. 314.

Thickness of Side Plates

The necessary thickness for side plates is readily calculated by considering the pressure on the ring at a certain depth due to the head of water, and by treating the tank as an ordinary thin cylinder subjected to internal pressure.

The following is the formula employed, which may easily be deduced from first principles :—

$$P \times D = 2fte$$

$$\text{or } t = \frac{P.D}{2fe}$$

Where P = pressure due to water in lbs. per square inch.

D = diameter of tank in inches.

f = allowable working stress (usually 5½ tons per square inch).

t = thickness of plate in inches.

e = the efficiency of the vertical riveted joints. Up to 90 per cent. for large holders. For small holders it ranges from 75 to 85 per cent.

The pressure P is found as before explained, namely,—

$P = wd$ lbs. per square foot, where

w = weight of a cubic foot of water = 62·4 lbs.

d = depth below surface of the *bottom* of the plate.

Thus, to calculate the required thickness of the bottom row for a tank 30 feet deep and 150 feet diameter we have—

$P = wd = 62{\cdot}4 \times 30 = 1872$ lbs. per square foot = 13 lbs. per square inch.

$$\text{then } t = \frac{13 \times (150 \times 12)}{2 \times 5\frac{1}{2} \times 2240} \times \frac{100}{90} = 1{\cdot}05 \text{ inches}$$

As regards the calculation of the efficiency of riveted joints this is a simple procedure, which may be found described in full in many books on structural design. The rivets should be checked for their stability in the way of resisting shearing and bearing stresses, whilst the plate at the joints must be sufficiently strong to preclude tearing, shearing or bursting through the edge. The efficiency of the joint

$$= \frac{\text{Least strength of joint}}{\text{Strength of solid plate}}.$$

It has been shown by experiment that in many instances the ultimate resistance of tank plates is less than the stress that would be necessary to overcome the friction at the joints, and that the friction is so great that within the limits of working stress there is neither shear in the rivet nor bearing stress against the shank. Such a condition applies, of course, to those cases where the rivet exactly fits the hole, and the work and design is of a first class character. An example of a typical vertical seam butt-joint is shown in Fig. 315.

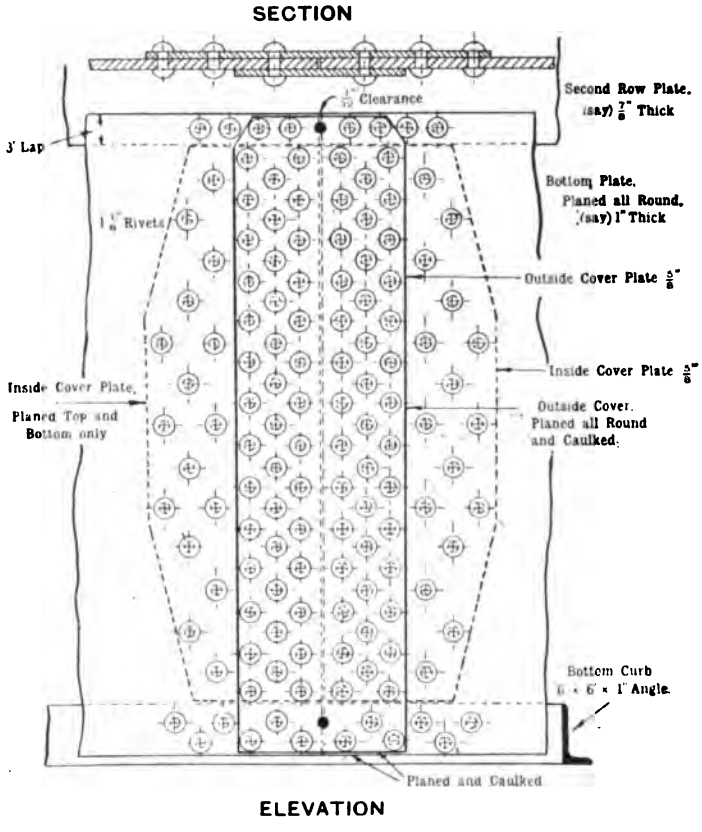

SECTION
Clearance
Second Row Plate. (say) 7/8" Thick
3" Lap
Bottom Plate. Planed all Round. (say) 1" Thick
1 1/8" Rivets
Outside Cover Plate 5/8"
Inside Cover Plate 5/8"
Inside Cover Plate. Planed Top and Bottom only
Outside Cover. Planed all Round and Caulked.
Bottom Curb 6" x 6" x 1" Angle.
Planed and Caulked
ELEVATION

FIG. 315.—VERTICAL SEAM BUTT JOINT FOR STEEL TANK.

TANKS WITH BULGING SIDES

One of the chief objections to the steel tank, when its depth becomes appreciable, is the necessity for providing plates of abnormal thickness, which are often difficult to obtain and cumbersome to handle. For this reason it has been suggested that the tank should be designed in such a manner as to permit of the side plates being of uniform thickness throughout, whilst the very thick plates common to the cylindrical tank could be dispensed with. The principle involved is that of curving or

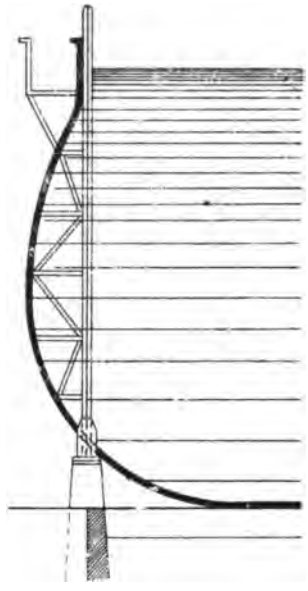


FIG. 316.—BONNET'S TANK WITH BULGING SIDES.

bulging the sides of the tank in such a manner that the horizontal stresses due to the head of water are transmitted to the top curb (which must, accordingly, be of stout construction) and to the tank floor. A tank of this description, designed on Bonnet's system, is seen in Fig. 316. It will be noticed that vertical posts are placed at intervals round the tank ring. The static pressure of the water is then transformed into—

(*a*) A horizontal pull at the base, this being balanced by the tension in the floor plates (*see* Fig. 317).

(*b*) A pull at the upper surface of the tank acting at a tangent to the curve at that point. This tangential pull will be distributed as a vertical downward thrust in the columns, and by a horizontal outward radial thrust in the top ring curb.

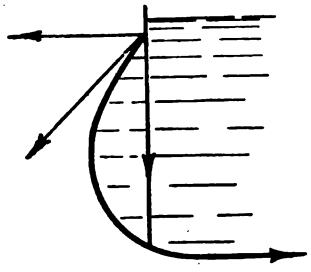


FIG. 317.

The principle of the method is undoubtedly interesting, but it has made little headway in practice. The most interesting example of a tank constructed on these lines is that at Simmering, in connexion with a holder having a capacity of nearly 5½ million cubic feet.

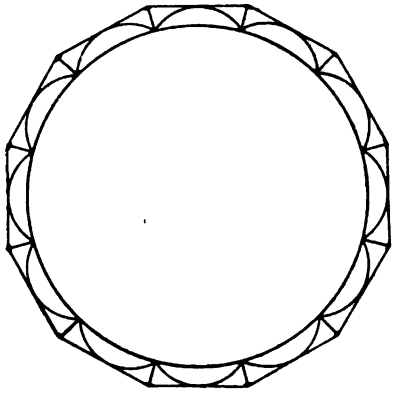


FIG. 318.—CRIPPS' FLUTED TANK.

F. S. Cripps has designed a tank for attaining the same object in which the sheets, instead of being bulged, are fluted. The sides are split up into a series of circular arcs of much smaller radius than that of the tank, with vertical posts at the intersections, the whole being united by a ring girder at the top. As pointed out by Cripps, however, the greatest objection to this type of construction is the enormous stress on the top girder (*see* Fig. 318.)

REINFORCED CONCRETE TANKS

Reinforced concrete as a material of construction for gasholder tanks has not made any great headway. The inherent principle of reinforced structures is that whilst the compressive stresses may be apportioned to the concrete the tensional forces must be provided for by the insertion of steel. In the gasholder tank the stresses are almost wholly tensional, with the result that the amount of steel required for reinforcement is no less than that required for the construction of a complete

steel tank. This statement must be qualified by the fact that the efficiency of the riveted joint must be taken into account, but in large steel tanks the heavier plates may have a joint efficiency of 90 per cent. It is agreed that even though this be the case the steel work is merely inserted in place in the concrete and, consequently, there is no riveting to be done. It is clear, however, that the cost of the concrete itself would be greater than the expense incurred for riveting.

When under construction there is considerable difficulty in getting the reinforcing bars into position, also in ensuring that the concrete forms a homogeneous mass round bars which must of necessity be closely pitched. The factor of safety must depend largely on these two conditions, for if the tank is carelessly constructed the tensional stresses will be falling upon the concrete instead of on the steelwork. The result is that cracks and leaks make their appearance. One of the great drawbacks to this type of tank is the time taken in construction, this being—from the time of commencement until the tank is ready for service—nearly twice that required with a similar tank made from steel. Probably the largest reinforced tank in existence is that erected at New York. This tank is 300 feet in diameter and 48 feet 3 inches deep.

It should be mentioned that reinforced concrete tanks develop minute hair cracks when the stress in the tensile members becomes excessive, in fact when the stress in the steel reaches 6,000 lbs. per square inch. The New York City Board, as a result of investigations with reinforced concrete cylinders, have limited the unit stress in the reinforcement of water-retaining structures to 8,000 lbs. per square inch.

THE COST OF GASHOLDERS

A large holder is much cheaper per unit of volume than is one of smaller dimensions. So far as the actual weight of metal is concerned the holder of light construction is not necessarily the cheapest, for there will in all probability be additional labour expenditure which will more than absorb any saving in material. Increasing the number of lifts, moreover, actually renders the holder bell more costly; but, in this case, there would be a reduced expenditure on tank and guide-framing, so that a three-lift holder will usually be cheaper than a two-lift holder of equal capacity. For very small holders a single lift is, as a general rule, the cheapest form of construction.

Per ton of metal the average cost of a gasholder varies between £19 and £22 in normal times, this figure including the whole structure and steel tank. As regards the individual items, much, of course, depends on size and design, but the total outlay will be accounted for somewhat as follows:—

Bell, complete	35 to 45 per cent. of total
Guide framing	18 to 23 „ „
Tank (steel)	35 to 45 „ „

Some interesting examples of the cost of existing holders are given here; but it must be remembered that as these holders were erected at a time when materials and labour were less expensive, the costs cannot be taken as indicative

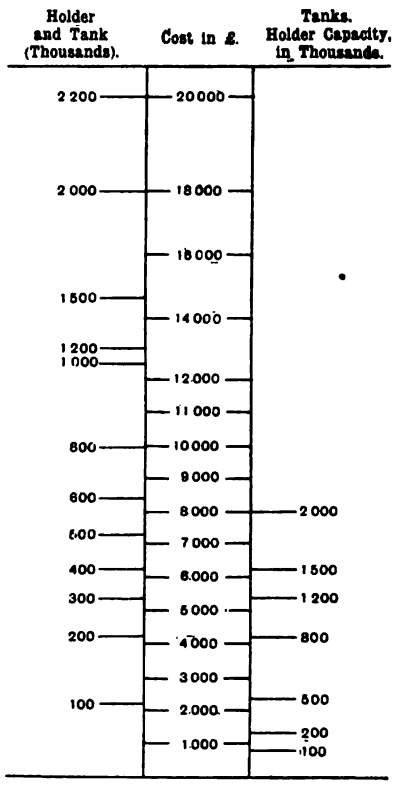


FIG. 319.

of present-day figures :—

	Approximate capacity.	Cost per 1,000 cubic feet contents.
East Greenwich .	12 million cubic feet	£5 5 0
Manchester . .	10½ „ „ „	£5 0 0
Berlin . .	8 „ „ „	£13 9 0
Vienna . .	8¼ „ „ „	£7 13 0

Single lift gasholders, with guide-framing, of small dimensions (say up to 50,000 cubic feet capacity) cost from £25 to £28 per 1,000 cubic feet, but if of the spiral type the cost would be about 25 per cent. less.

Two-lift holders of about a quarter of a million cubic feet capacity range from £16 to £20 ; or if spirally guided about £10 per 1,000 cubic feet. Holders of the most usual size as found in provincial works, those of 2 to 3 million capacity, cost from £9 to £12 per 1,000 cubic feet.

The cost of the tanks varies in accordance with their size and design, and with the prevailing costs of steel, brick and cement.

The following are typical instances :—

	Brick and Puddle.	Concrete Rendered.	Steel.
For 2 million cubic feet holder—			
Cost per 1,000 cubic feet holder capacity	£5 10*s.* to £7	£5 to £6 5*s.*	£4 to £4 5*s.*[1]
Cost per cubic foot tank capacity .	4½*d.* to 6*d.*	4·2*d.* to 5·3*d.*	3·3*d.*
For 1 million cubic feet holder—			
Cost per 1,000 cubic feet . . .	—	—	£4 10*s.*[1]
Do. for ½ million cubic feet holder .	—	—	£5 5*s.*[1]
Average cost of tank for 1 million cubic feet holder			
Per 1,000 cubic feet capacity. . .	£6 5*s.*	£5 15*s.*	£4 10*s.* + 17*s.* 6*d.* foundations = £5 7*s.* 6*d.*
Per cubic foot tank capacity . . .	6·3*d.*	5·7*d.*	3·4*d.*

[1] Add foundations 17*s.* 6*d.* to 35*s.* in each case.

The diagram (Fig. 319) shows the relation between the cost of gasholders and their capacity, also the cost of steel tanks.

THE PRESSURE THROWN BY A GASHOLDER

The pressure thrown by a gasholder is dependent upon the weight of the floating portion and its diameter. Thus, if the total weight of the bell, including the weight of the water in the lutes, is W tons and the diameter of the holder is D feet the pressure may be calculated as follows:—

$$\text{Maximum pressure in inches of water} = \frac{549\,W}{D^2}.$$

A single lift holder usually throws from 3 to 4 inches of water pressure, while in the case of a telescopic holder the top lift will throw about the same amount, with each succeeding lift throwing about 2 inches. When dealing with multiple lift holders a figure comparing very closely with the actual pressure thrown in practice may be obtained by considering the total weight and the mean diameter of the holder, although this is not strictly accurate. Theoretically, the weight of the bell, when the holder is fully inflated, acts on the greatest area, i.e. the area obtained by considering the diameter of the lowest lift. In practice, the pressure thrown by the inner lift alone is the chief consideration.

THE CONTAMINATION OF GAS IN HOLDERS

It occasionally happens that coal gas, although found to be perfectly clean at the outlet of the purifiers, shows decided traces of sulphuretted hydrogen at the holder outlet. Fortunately, such an occurrence is comparatively rare in this country, but one London company experienced considerable annoyance in this respect some few years ago. The pollution of gas in this way is the result of the spontaneous production of sulphuretted hydrogen in the gasholders, or, less commonly, in station meters. Although no positive reason can be ascribed for the formation of the impurity, it seems extremely probable that it may be due to the presence of certain micro-organisms, or to an electrolytic action set up by the iron plates. It is, of course, a recognized fact that certain bacilli characteristic of ordinary water possess the property of decomposing definite salts (such as calcium sulphate, present in the water), with the evolution of sulphuretted hydrogen. A series of experiments conducted on water taken from a gasholder tank seemed to corroborate the organic theory, the bacteria deriving their necessary food supply from dead iron organisms. In the case of the London company, complete immunity from the trouble was obtained after the bacilli had been destroyed by means of a germicide, such as sulphate of copper. The French investigator, M. Guillet, has concluded that contamination is also caused by exposure of the gas to a clean iron surface resulting from the detachment of rust. He has shown that in the presence of the bare metal the carbon disulphide in the gas reacts with carbon dioxide and water, with the liberation of sulphuretted hydrogen. The remedy suggested in this case, however, is somewhat inconvenient, as the holder must temporarily be put out of action. It entails the soldering of zinc sheets to the iron plates at definite places, when galvanic action checks the formation of the sulphuretted hydrogen.

CHAPTER XVIII

WATER GAS

MANUFACTURE, ENRICHMENT, AND USE

In the year 1793 Lavoisier discovered that when steam is passed over incandescent carbon, the carbon is oxidized and carbon monoxide and hydrogen are produced. The modern water-gas plant is wholly dependent upon this principle.

Water gas must be looked upon as essentially an auxiliary to coal gas, and in this capacity it has been adopted by a large number of gas undertakings as a means of providing for increase of business and occasional sudden demands. Water gas, manufactured on the Lowe principle, was introduced into this country in 1890, although prior to this it was experimented with for some fifty years without any very favourable or convincing results. Water gas was, at the outset, adopted on account of its comparative cheapness as an enriching medium as compared with the methods then in vogue. Its introduction naturally met with a good deal of opposition from the conservative gas engineer, but its utility gradually became self-evident, insomuch that it is now present in most town gas to an extent of from 15 to 30 per cent. by volume. At the present time carburetted water gas is looked upon rather as a useful auxiliary for dealing with the "peak" load; for enrichment has largely lost its significance in present-day practice. The rise in price of the enriching oil is largely due to the extended uses to which residue petroleums are now put, and to the comparatively high freightage rates prevailing. Instead of costing about 2*d*. per gallon, as in 1910, the price of the oil has in the last year or so risen to as much as 5*d*., or even 10*d*., per gallon. For this reason the proportion of water gas intermixed with coal gas has in many cases undergone considerable reduction; in fact, some works did at one time cease to make it altogether. The annual output of water gas in the whole world, nevertheless, amounts to about 150,000 million cubic feet.

The benefits derived from the use of water gas as an auxiliary to coal gas may be summarized as follows:—

1. Low capital outlay per unit of capacity. Including relief holder the outlay on a carburetted water-gas plant of large capacity would amount to about one-third that entailed by a coal-gas plant of similar capacity.

2. The ground space occupied by the plant is considerably smaller than the area covered by equivalent coal-gas plant. The ratio of the areas required may, in fact, be so great as 9 to 1.

As regards ground area required, Shelton gives the following figures :—

Capacity of Plant.	Ground area required.
100,000 cubic feet per diem . . .	4 square feet per 1,000 cubic feet.
200,000 „ „ . . .	3·5 „ „ „
400,000 „ „ . . .	2·75 „ „ „
600,000 „ „ . . .	2 to 2·5 „ „ „
7 to 10 million „ . . .	1·25 to 1·5,, „ „

These figures include scrubbers and condensers, but not boiler house, engine room, or relief holder.

3. Sudden demands, such as those due to fog and other unforeseen contingencies, may be easily and quickly coped with. A water-gas plant may be picked up from cold in rather more than three hours. Retort benches require three days to bring them up to working heats.

4. The expense of retort benches constantly under slow firing is obviated.

5. The quality of the gas made is easily regulated to the requirements of the moment.

6. The proportion of water gas intermixed with the coal gas may be varied in accordance with the demand for coke. Thus, a water-gas plant possesses a controlling influence over the coke market, and large stocks of this by-product may to some extent be avoided.

7. The fact that a considerable proportion of the gas may be manufactured from coke in lieu of coal places the works in a position of rather greater independence so far as coal supplies are concerned.

8. In these days of labour upheavals the small amount of manual work required with a water-gas plant is a prominent consideration. The item of wear and tear, both in the direction of labour and materials, is low in comparison with the ordinary machine-charged horizontal retorts.

9. The sulphur impurities in the gas are low in comparison with the same impurities in crude coal gas. As regards sulphuretted hydrogen, crude coal gas contains on an average 500 to 800 grains per 100 cubic feet, and crude water gas 120 grains. Of carbon disulphide and other sulphur compounds coal gas contains from 35 to 50 grains, and carburetted water gas 10 to 15 grains per 100 cubic feet.

10. In many instances carburetted water gas has proved itself effective in diminishing trouble from naphthalene deposits. It is said that the carburetted gas acts as a solvent vehicle for naphthalene and, accordingly, prevents its precipitation from the coal gas. Much, however, would appear to depend upon the temperature at which the carburettor and superheater are operated, for if the light oil vapours are submitted to too great a temperature, over-cracking will occur and the virtue of the gas as a naphthalene sedative is likely to be lost. Again, of course, much will depend upon the proportion in which the carburetted gas is present. At any rate, water gas as a naphthalene eradicator must not by any means be looked upon as infallible.

As regards the inherent disadvantages of water gas it is not possible to compile a very formidable list; but, first, mention must be made of the very high per-

centage of noxious gas, carbon monoxide, which it contains, the proportion amounting to three or four times as much as that to be found in coal gas. The objection is, no doubt, one which is largely discounted in the present day, for the many years' experience of water gas shows no tendency towards any increase in the number of deaths from asphyxiation. A further disadvantage lies in the fact that, at the time of writing, the expense of manufacture of carburetted gas is greater than that of coal gas owing to the very considerable increase in the cost of oil.

The smooth operation of a water-gas plant may be quickly upset by the introduction of an inferior coke, and its somewhat sensitive nature in this respect is liable to give trouble in those works where a high-class coal, with a low ash-content, is not always procurable. In some works it is customary to set aside the coke from the higher quality coals for the exclusive use of the water-gas plant. It is frequently urged as a merit of carburetted water gas that its permanence is a great recommendation in preventing any deterioration of or deposition from the district gas as it passes through the street mains. On the other hand, the author's experience goes to show that any slight imperfection in the fixing chambers, or any insufficiency of condensation, may be followed by a very appreciable drop in illuminating power during the passage of the gas through the district mains. Deterioration of the kind may, however, be guarded against by operating both carburettor and superheater at their correct temperatures, and by attending to the periodical cleaning and re-chequering of these vessels. The condensers, too, must operate on efficient lines, so that the temperature of the gas is reduced as near as possible to that of the atmosphere before entering the oxide purifiers.

S. Carter has pointed out that 70° Fahr. may be looked upon as a critical temperature in the process, and that with gas leaving the purifiers at this temperature oil will be precipitated in the holders.

THEORY OF MANUFACTURE

The generation of water gas depends upon the action of steam upon red-hot carbon, the latter being present in the form of coke (containing about 90 per cent. of carbon). As is well known, water, or steam, cannot be decomposed by the action of heat alone; but if subjected to heat in the presence of a reducing agent the oxygen will combine with this agent, with the evolution of hydrogen in the free state. Heated carbon possesses a greater affinity for oxygen than does the hydrogen with which the oxygen is combined in the form of steam. Hence the sequence of reactions which result. The oxygen of the steam combines in the first place with the carbon to form carbon dioxide, and some carbon monoxide. Thus, in the lower portions of the fuel bed we have the following reactions:—

$$\begin{cases} (a)\ C + 2H_2O = CO_2 + 2H_2. \\ (b)\ C + H_2O = CO + H_2. \end{cases}$$

According to the generally accepted theory the carbon dioxide is subsequently "reduced," by combination with another carbon atom, during its travel through the remainder of the fuel bed:—

$$(c)\ CO_2 + C = 2CO.$$

The reduction of carbon dioxide to carbon monoxide in this manner is, however, never quite complete, with the result that from 3 to 4 per cent. of the former gas is found in the finished product. The quantity of carbon monoxide formed by direct reaction at the base of the fuel bed will largely depend upon the temperature prevailing in that portion.

A study of the thermal nature of these reactions is important, for in this way the principle of the operation of modern apparatus may be best explained. The reaction (*a*) for the production of CO_2 absorbs heat, as also does (*b*) which accounts for the direct formation of CO. By far the greatest proportion of heat is, however, absorbed by the so-called reducing action (*c*). The first reaction (*a*) will not occur at temperatures less than about 1,100° Fahr., whilst slightly higher temperatures still are required for reactions (*b*) and (*c*). It may be seen, then, that, in order that the required reactions shall take place, the fuel bed must, in the first instance, be raised to a definite temperature; and, in order that the reactions may continue, the temperature must be maintained above a certain minimum in the face of a series of endothermic changes. Means wherewith the temperature is maintained by intermittent operation is now almost universally adopted—the gasmaking period, having a duration of a few minutes, being followed by a spell of heat recuperation, technically known as the "blow." At the completion of the gasmaking "run," the steam is shut off from the fuel bed, and a blast of air takes its place. The oxygen of the air, combining with the hot carbon, is then directly converted into CO_2:—

(*d*) Blow reaction:—

$$C + O_2 = CO_2.$$

As is well known, this reaction is exothermic in nature, the approximate quantity of heat evolved amounting to 13,500 B.Th.U. per lb. of coke consumed. By the continuance of the "blow" for a definite period, usually rather more than half that of the gasmaking "run," the temperature of the bed and of the surrounding brickwork is restored. The part played by the substantial firebrick lining must not be overlooked. These walls, once they are heated through, form a reserve of heat which is available to be drawn upon during the gasmaking period.

WATER-GAS SYSTEMS

The systems which have been introduced for the purpose of manufacturing water gas may be classified under the following three headings:—

(1) The Continuous System.
(2) The Intermittent System.
(3) The Neat-Oxygen Method.

Of these, the intermittent method is the only one to which serious consideration is given to-day. The continuous system, in which it was sought to replace the lost heat by independent external firing, received much attention in the early days of water gas; and was in one respect to be commended, in that it endeavoured to provide for the uninterrupted manufacture of the gas and obviated the periods

of blowing. Practical difficulties, heat losses by radiation, and general inefficiency, however, soon sounded its knell, with the result that there are no examples of the method now extant. The intermittent process, with "run" and "blow" succeeding each other at regular intervals, has shown itself, by the test of time, to be the only practicable method.

A scientific and by no means impracticable system is that embodying the use of neat oxygen. The process operates on continuous lines and results in a gas practically free from nitrogen, but containing from 65 to 70 per cent. of carbon monoxide. Steam is admitted to the base of the generator in the ordinary manner; and, along with it, is passed a stream of pure oxygen. In this way, whilst steam is combining with a portion of the carbon to form water gas, the heat lost by the endothermic nature of the reactions is replaced by the exothermic combination of the oxygen with part of the carbon. If steam and oxygen are regulated in accordance with theoretical requirements the process will proceed with little trouble. The chief drawback, which has as yet prevented the system from making any great headway, is the impossibility of obtaining oxygen at a price which would permit the gas to compare in cost with that produced by the more general methods.

Some mention should be made here of the distinction between carburetted water gas and oil gas, the latter misnomer being still in somewhat common use for the former product. Oil gas, in the true sense of the name, is the gaseous mixture of hydrocarbon vapours resulting from the direct conversion of oil into gas, in an iron retort, such as takes place in the Peebles and Pintsch processes. In this way a gas having an illuminating power of from 60 to 70 candles is obtained. An important feature of such processes is the further washing of the gas in oil, whereby any vapours not rendered permanently gaseous are removed. This oil is returned to the retort again and again, the residue remaining behind as a coke. In this country the process has chiefly been applied in connexion with the well-known Scottish shale oils, about 100 cubic feet of gas being obtained from one gallon of the oil. In countries where a mineral oil is only obtained with some difficulty the gas has been produced from animal or vegetable varieties.

TYPES OF WATER-GAS PLANT

The plants now in use for the purpose of generating water gas are many and varied. In general, however, the apparatus may be classified under two distinct headings, namely:—

(*a*) Plants employing an enriching agent, *i.e.* carburetting plants.

(*b*) Plants in which no enrichment of the gas takes place, *i.e.* "blue" gas plants.

It must be understood, however, that with the carburetting plant "blue" gas may, if so desired, be readily produced, and in the same way many of the recognized "blue" plants are now fitted with a small carburettor, which enables them to yield enriched gas. In addition to the above apparatus, mention must be made of the more modern and, as yet, little known plant known as the "Methane-Hydrogen" system, and such plants as that of Strache, which entail the complete

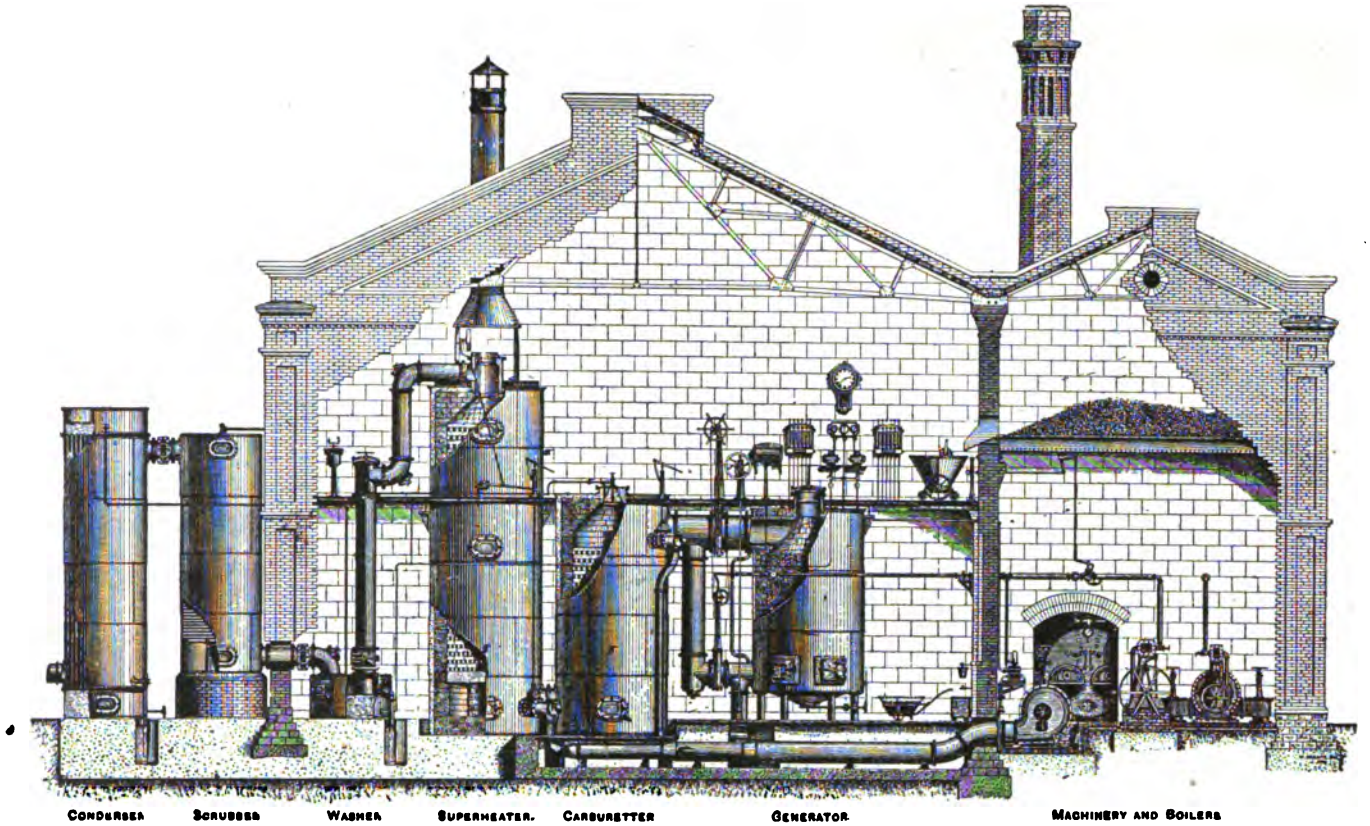


FIG. 320.—DIAGRAM SHOWING CONSTRUCTION OF HUMPHREYS AND GLASGOW WATER-GAS PLANT.

gasification of coal. These are discussed later. Of the carburetting plants, that originally introduced in the United States by Lowe, and improved by Humphreys and Glasgow, has undoubtedly gained the greatest popularity.

The apparatus (Fig. 320) consists of a generator, carburettor, superheater, oil-heater, washer or seal, and condenser. The generator, carburettor, and superheater are cylindrical in shape; the shells are formed of $\frac{3}{8}$-inch steel plates, and are

FIG. 321.—A SMALL HUMPHREYS AND GLASGOW INSTALLATION.

lined with special firebricks. In order to reduce to a minimum the heat lost by radiation, an annular space, about two inches wide, is left between the shell and the firebrick lining, and this is tightly packed with slag wool. The generator is charged through a circular door in the top; cast-iron doors being provided at the base for the removal of the clinker. A two-way pipe, the function of which will be explained later, connects the generator and carburettor. Fitted to the top of the carburettor

is a centrifugal oil spray. A steam pump, connected with the storage tank, delivers oil to the distributor at a pressure of about 60 lb. per square inch, the oil having been previously passed through the heater and considerably raised in temperature. Both the carburettor and superheater are filled with firebricks laid chequer-wise, the disposition of the bricks affording extensive heating surface for the permanent gasification of the oil. A stack valve is placed at the top of the

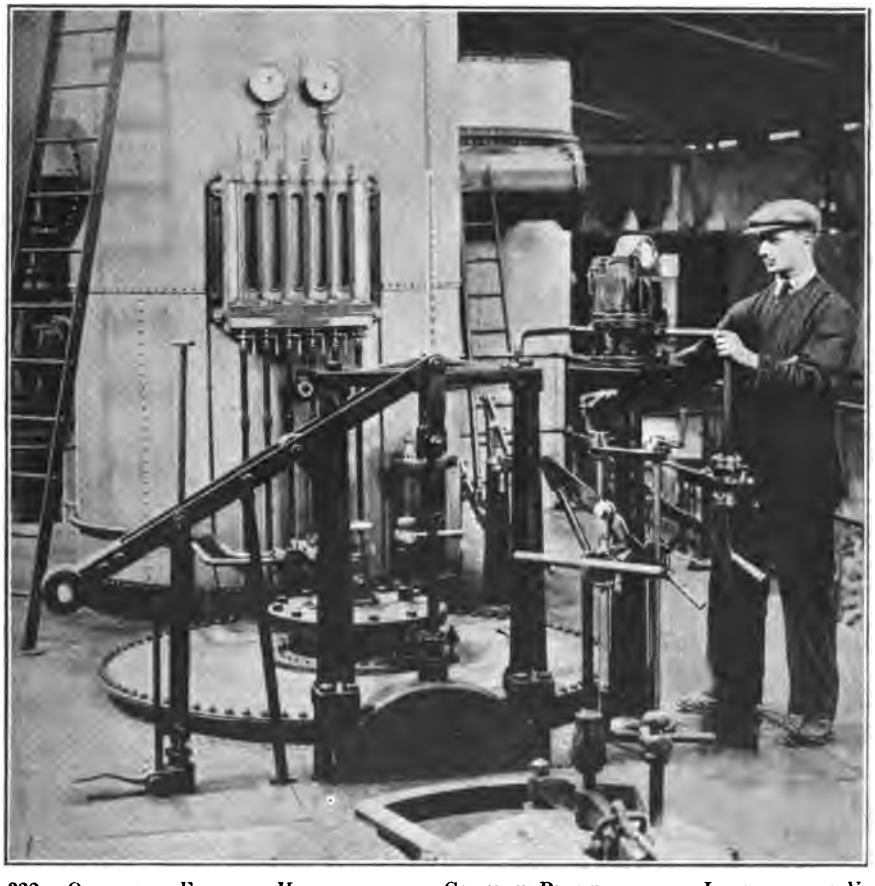


FIG. 322.—OPERATING FLOOR OF HUMPHREYS AND GLASGOW PLANT, SHOWING INTERLOCKING VALVE-GEAR, GAUGES, ETC.

superheater, and through this the final products are expelled during the "blow"; during the "run" this valve is closed, and the carburetted gas makes its way through the remainder of the apparatus. As will be seen from the figure, the oil heater is placed in the outlet pipe from the superheater and meets the full volume of the hot gas. With the exception of clinkering, the plant, in all but the smaller installations, is entirely manipulated from an elevated floor, flush with the top of the generator, and all valves, levers and gauges are collected at this level. Any

risk of the operator moving the wrong levers is obviated by the insertion of a special interlocking valve-gear.

A special feature of the apparatus is the reversal of the " run " in the generator, so that steam may be admitted either below the coke-bed or above it ; it is to enable this to be done that the two-way pipe, previously referred to, is employed.

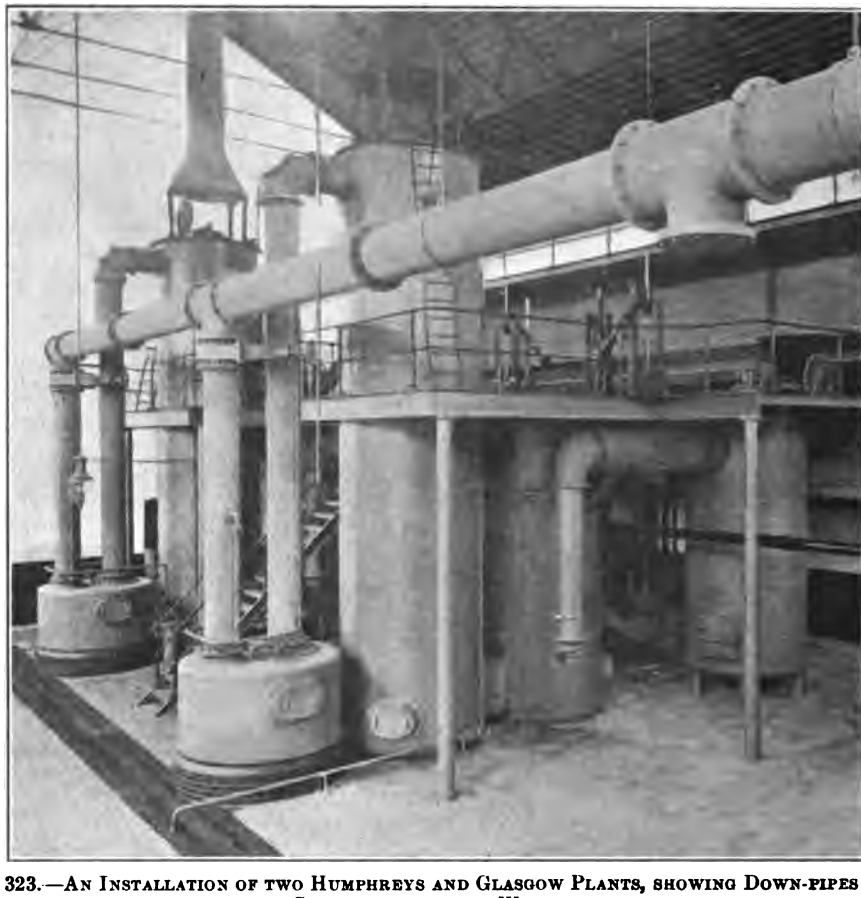


FIG. 323.—AN INSTALLATION OF TWO HUMPHREYS AND GLASGOW PLANTS, SHOWING DOWN-PIPES FROM SUPERHEATERS, AND WASHERS.

Experience shows that if steam is continually admitted to the base of the generator, in time the lower portion of the fuel bed, which has continually to perform the heaviest duty of decomposition, becomes cool and inactive, the steam condensing instead of being converted into gas. The succeeding " blow," therefore, instead of rekindling the fire, chills down the lower layers of coke still more. To rectify this, after every few runs the steam is admitted above the fuel and makes its way downwards and thence to the carburettor as usual. The reversal of flow is

completely effected in one movement, the valves being controlled by interlocking gear which renders confusion or mistake impossible. The function of the washer, which corresponds to the hydraulic main of the coal-gas plant, is to provide a safety seal which precludes the gas from being pushed back into the superheater (by the pressure thrown by the relief holder) during the periods of the "blow." The washers are well illustrated in Fig. 323. The purpose of the scrubber and the condensers is to remove the vesicles of tar and oily matter which remain suspended in the gas, and to cool the gas down to a normal temperature prior to condensation.

The Humphreys and Glasgow plants are made in sizes ranging from 100,000 cubic ft. to 3 million cubic ft. per twenty-four hours. One of the most interesting installations is that at the Beckton gasworks. In this case the plant, consisting of

FIG. 324.—BECKTON PLANT, SHOWING LEVERS FOR HYDRAULIC OPERATION.

five sets, has a maximum capacity of 18 million cubic feet per diem, and the whole of the operation is performed by means of hydraulic power, which controls all valves, at a pressure of 500 lb. per square inch. The gasmaker attached to each unit has merely to stand at his station, and by the turn of a lever can change from cycle to cycle. The working floor of the Beckton plant is seen in Fig. 324.

SINGLE SUPERHEATER PLANTS

A good deal of attention has been given to the single superheater type of plant, some examples of which now exist in this country. In such plants the carburettor and superheater are merged into a single vessel of rather larger capacity than the superheater of the more common plant. There is some conflict of opinion as to which

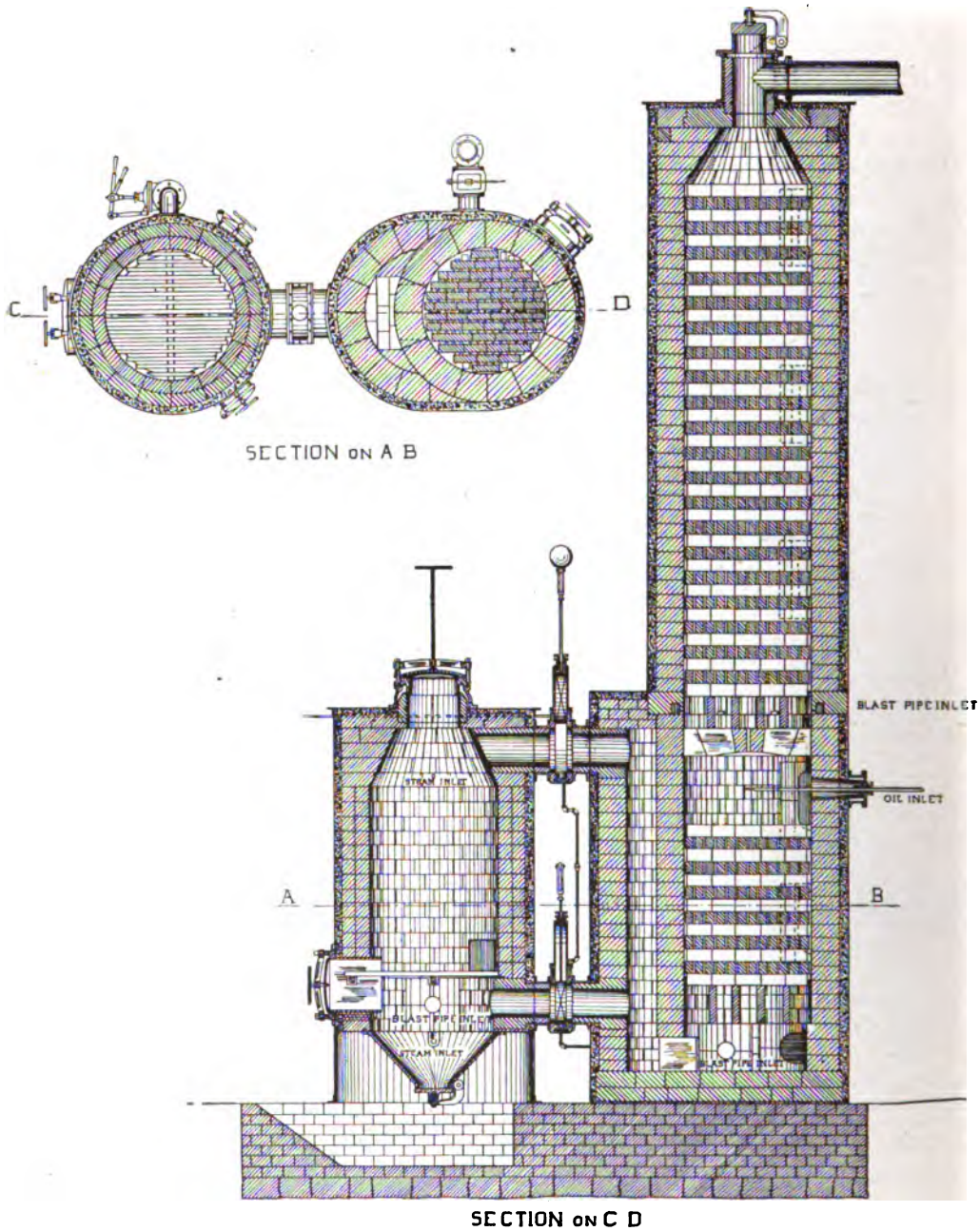


FIG. 325.—SINGLE SUPERHEATER PLANT, MERRIFIELD-WESTCOTT-PEARSON TYPE.

method is to be preferred from the point of view of getting the utmost efficiency from the oil, but the single superheater plant is certainly less costly in the first place.

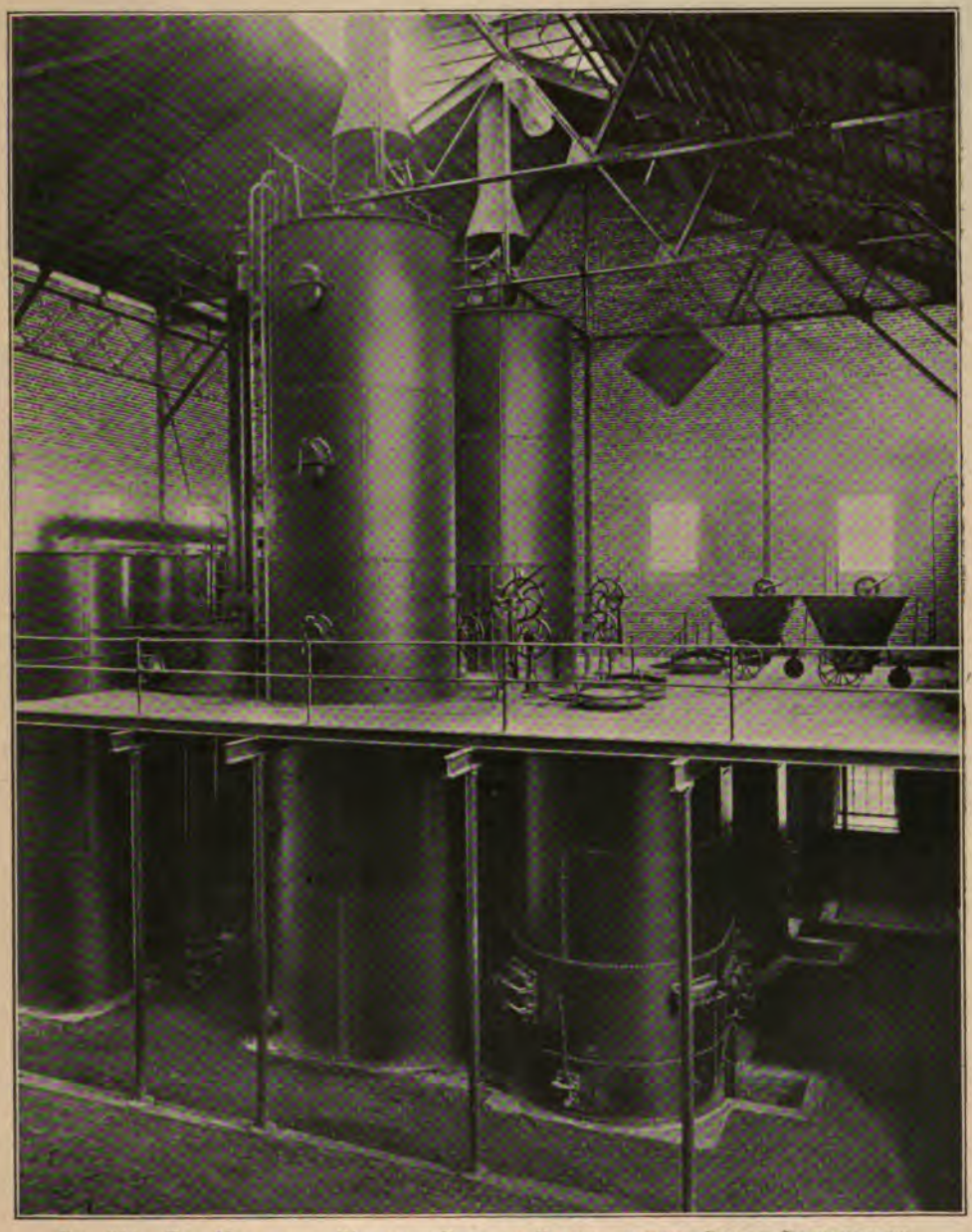


FIG. 326.—THE MERRIFIELD-WESTCOTT-PEARSON PLANT, SHOWING SINGLE SUPERHEATER.

In this type of plant, it has been said that by introducing the oil at an intermediate point in the superheater the more volatile constituents separate out immediately, ascend, and make their escape before undergoing decomposition. Meanwhile, the heavier constituents of the oil fall to the base of the vessel and are then swept

forward again by the current of water gas entering from the generator, traversing the entire height of the chamber.

The most important plant operating on this principle in this country is that known as the Merrifield-Westcott-Pearson. As before explained, it differs from the double superheater plant in that the carburettor and superheater consist of one vessel, and the oil is injected at three distinct points round the periphery of the vessel instead of from one spray at the top. The oil, moreover, is sprayed in a direction contrary to that of the gas, whereas in the Humphreys plant it travels with the gas. An additional feature is that the hot gas passes through the condenser before being scrubbed, while in the original installations the main valves were cooled by a system of water circulation. The advocates of the double superheater system point out that the primary consideration affecting the economical gasification of oil is that the oil shall be exposed, at a high rate of travel, to a proper fixing surface at a moderate and carefully adjusted temperature. Accordingly, this surface must consist of length in the direction in which the gas travels, rather than of cross-section; for the vapours must never approach a condition of rest in contact with the hot surface in the fixing chambers. For this reason, the oil should be introduced with, and not against the current of gas.

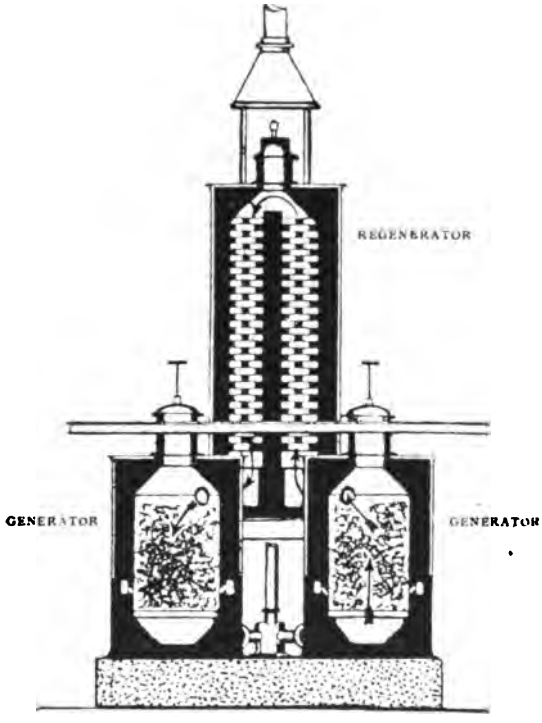


FIG. 327.—THE "K. & A." BLUE GAS PLANT.

"BLUE" WATER-GAS PLANTS

Of the "blue" water-gas plants, the Kramers and Aarts apparatus, and also the Dellwik plant, have been extensively adopted on the Continent, and both plants have made some headway in this country.

The former plant—known as the "K. & A."—is unique in that the generator is composed of two vessels, and, while during the "run" these are used in series, during the "blow" they are worked in parallel. It is found that this device permits the period of blowing to be about one-quarter of that required in the plants previously described, and therefore the time of gasmaking is correspondingly increased. A section of the apparatus is depicted in Fig. 327, and by referring to this the system of working can be readily followed. It will be noticed that between the two gener-

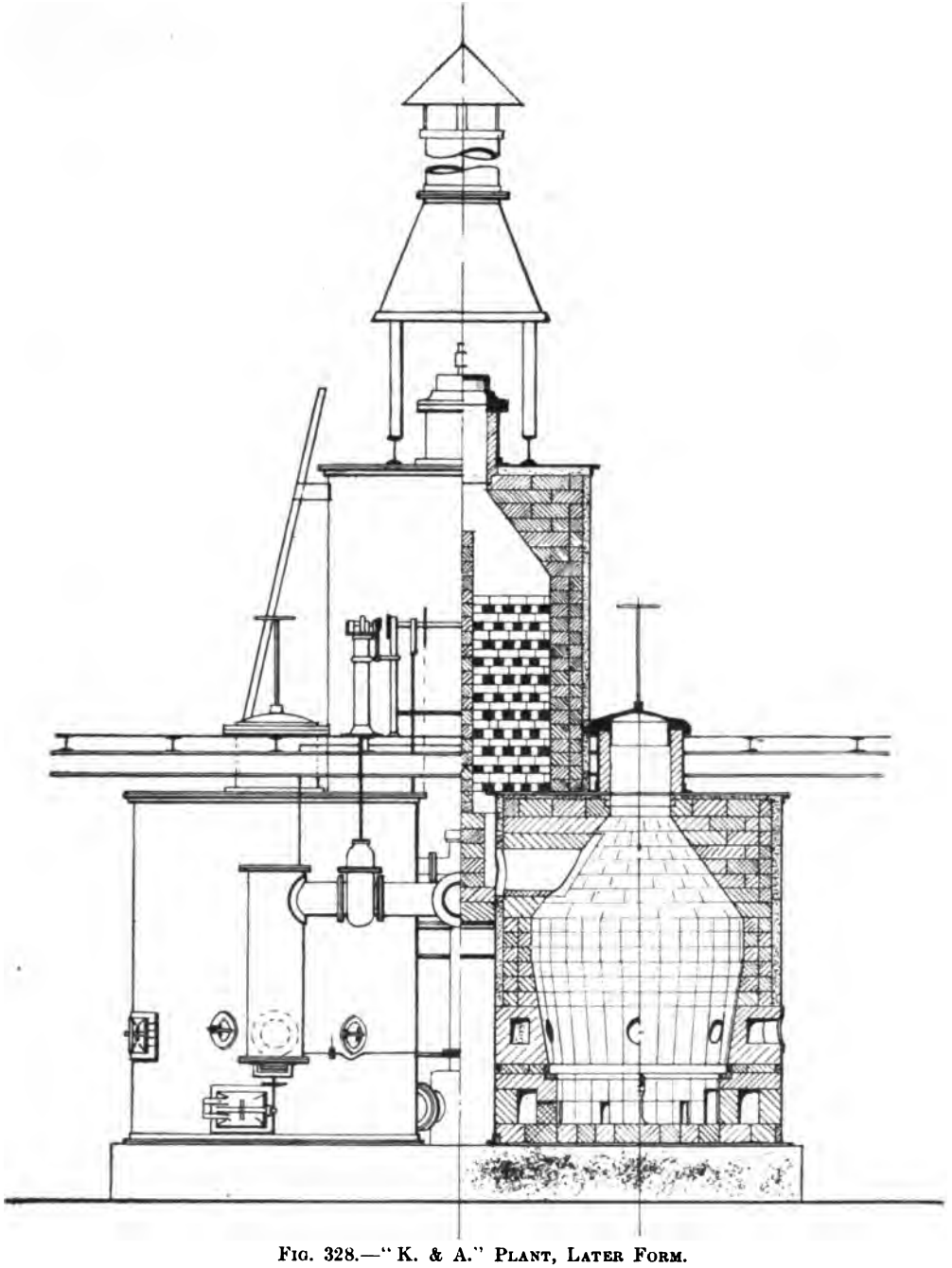


FIG. 328.—"K. & A." PLANT, LATER FORM.

ators, a third vessel, known as a regenerator, is interposed. During the "blow," this is heated up by the hot gases from the fires. During the "run," steam

is introduced to one of the generators and is converted into carbon dioxide and monoxide; it then traverses the regenerator, where the surplus steam is split up and the gas super-heated; finally it makes its way through the second generator, in which the carbon dioxide is reduced to carbon monoxide. For the next run the direction of the steam is reversed, that is, the final generator now becomes the first.

This system combines a shallow fuel bed for the blast, together with a deep fire and long contact with the incandescent coke during the "run." The fact that while

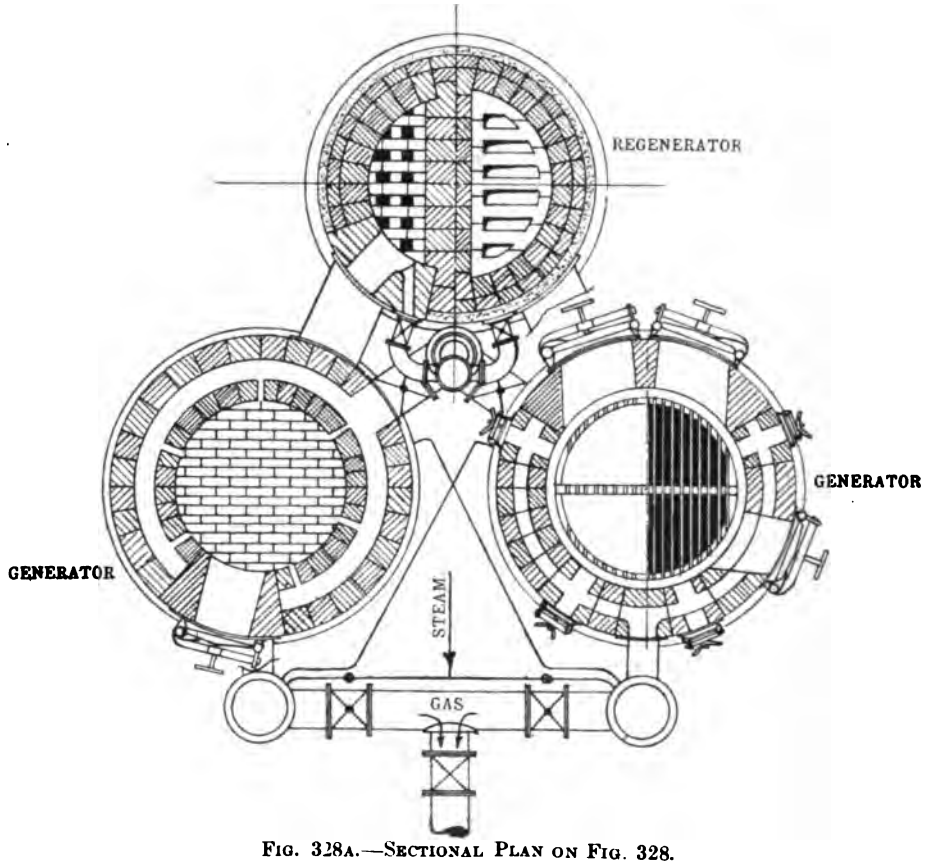


FIG. 328A.—SECTIONAL PLAN ON FIG. 328.

during the "blow" a shallow bed of fuel is required and during the "run" a deep fire is desirable has proved a difficulty to many designers of water-gas plant, but the introduction of the split generator has effectively overcome this.

It is interesting to note that in the large hydraulically controlled installation at the Beckton works the units are fitted with generators on the "twin" principle, and that by the movement of a lever the generators may be set during the "run" for operating either in series or in parallel. In this case the generators are no more shallow than is the ordinary single generator, and the chief advantage lies in

the fact that when they are operated in parallel during the "run" the capacity of the plant is increased by some 25 to 30 per cent. On the other hand, when the demand for gas may be less they can be steamed in series, when a rather better quality gas containing a smaller percentage of CO_2 will be obtained.

The Dellwik blue-gas plant (Fig. 329), while yielding a gas very similar to that produced in the "K. & A." apparatus, materially differs from it in construction. In this case there is a single generator preceded by a superheater through which the steam passes before entering the generator. It will be noticed that the door at the top of the generator performs the double duty of a stack valve and charging door for replenishing the coke. The gas passes direct from the generator to the superheater, and thence through a coke scrubber. As in the other plants, an interlocking valve-gear precludes the possibility of any danger which might arise from carelessness on the part of the operator.

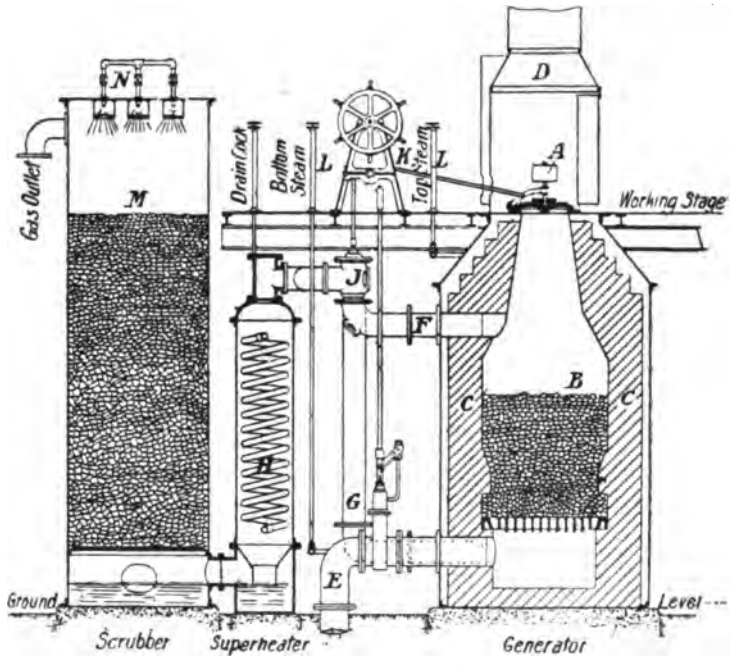


FIG. 329.—DELLWIK "BLUE" GAS PLANT.

In this process the air supply from the blower is most carefully regulated, and the level of the fuel bed should be kept constant.

PRODUCTS OF THE "BLOW"

In the Dellwik plant an endeavour is made to so regulate the air-blast and fuel bed that the products of the "blow" consist almost solely of CO_2 and nitrogen. When air is admitted to the base of a deep fuel bed, CO_2 is formed in large proportion in the first place, but on travelling through the remainder of the fuel, it is partially reduced to carbon monoxide, so that a semi-producer-gas results. The percentage of CO present in the products varies inversely with the speed of the blast, and directly with the depth and temperature of the fuel bed. At first sight the presence of CO might appear to be a distinct disadvantage, for it is produced by allowing an endo-

thermic reaction to take place during the period when maximum heat expulsion is desirable. Moreover, by burning carbon to CO_2 about three times as much heat is evolved as when it is burnt to CO only. It has to be borne in mind, however, that in the majority of plants the case of succeeding apparatus comes in for consideration. For instance, in the Lowe plant the generator is followed by two vessels which themselves must be raised to a high temperature; whilst in the "K. & A." plant there is the regenerator to be heated up. Thus, the producer gas issuing from the generator (or generators, in the case of the twin plants) is burnt, by admitting a small quantity of secondary air from the blast main, in the succeeding vessels, maintaining these at the desired temperature. The average composition of the "blow" gases issuing from the generator when the fuel bed of the latter is moderately deep is as follows:—

Carbon monoxide	17	per cent. by volume.
Carbon dioxide	10	„ „
Nitrogen	73	„ „

Traces of hydrogen and methane may also be found.

Working with a fuel bed of 6 feet 6 inches in the Lowe type plant, the author finds the following result:—

"BLOW" GASES

	CO_2.	CO.
End of 1st minute	18·6 per cent.	2·9 per cent.
„ 2nd „	14·6 „	9·4 „
„ 3rd „	12·0 „	16·4 „
„ 4th „	7·6 „	19·8 „

From this it will be seen that the quality of the producer gas is gradually undergoing improvement as the blow proceeds and the fire becomes hotter.

The main overhead blast pipe, with connexions leading to the carburettor and superheater, is seen in Fig. 321.

As regards apparatus for providing the blast, this in the early days of water gas invariably consisted of an open fan driven by a high-speed reciprocating steam engine. The speed of the fan is usually in the neighbourhood of 2,000 revolutions per minute. For modern work the reciprocating engine has been almost entirely superseded by the steam turbine; or, in isolated cases, by electric motors. The de Laval steam turbine coupled to a Sturtevant fan (Fig. 330) is the most common form in use. In this case the speed of the turbine is geared down in a ratio of 10 to 1 so as to give the requisite speed at the blower. Another form of blower which is coming into favour is that designed on the Rateau principle, which appears to provide somewhat greater efficiency in the direction of blast. As regards the electric drive, this has proved quite suitable, but it cannot be said that it affords the same elasticity as is obtained with the steam motor. The question of providing a "positive" blast is one which has engaged the designers of water-gas plant. The ordinary open fan, such as the Sturtevant type, is not a pressure-raising device, and merely propels a current of air through spaces which may be open to it. Accordingly, if

the main outlet pipe is suddenly closed the pressure will rise from 1 inch to 2 inches only. "Positive" blowers, on the other hand, are pressure-raising devices enclosed by a casing. Thus, if the main outlet was closed the pressure in the casing and pipe would go on building up until something gave way, or the engine was pulled up. The most notable example of these blowers is the Roots type. Dellwik plants invariably employ a positive blast, and in this way it is said that rekindling can be done more rapidly, and, therefore, the duration of the "blow" may be curtailed. When such a blower is used, however, it is essential to fit a safety-valve on the main blast pipe.

Explosions in the blast main, occasionally resulting in the wrecking of the fan, are by no means an unknown occurrence. They are essentially the outcome of a badly

FIG. 330.—TURBO-DRIVEN WATER-GAS FAN.

fitting hot-gas valve, *i.e.* the valve between blast main and generator, which may permit a small portion of water gas to get by during the down runs. This gas, meeting with the air in the blast main, forms an explosive mixture, which may be ignited by a spark from the fan. A safety appliance, designed to minimize the damage caused by such a contingency, is shown in Figs. 331 and 332. It consists of a cast-iron flap swinging in a special box which is attached to the outlet of the fan. During the time when the blower is at work the flap remains in the position shown. Should any explosion occur in the blast main the force of it drives back the flap on to its seating, thus protecting the fan from damage, and expends itself by breaking through the canvas panels of the box.

It is customary on water-gas plants for the blower engines to remain running

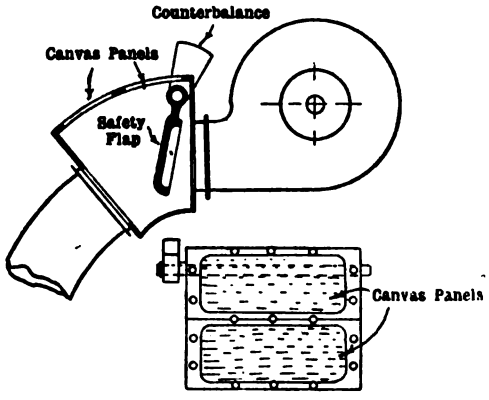


FIG. 331.—DETAIL OF FIG. 332.

at full speed during the period of the "run," when they are performing no useful work. Those having an eye to small items have pointed out the wastefulness of such procedure, with the result that in some instances a cut-out is arranged to reduce the consumption of steam in the blower engine while the run is proceeding. The arrangement may be easily effected in the case of turbines, but it presents a greater problem with reciprocating engines. There is, moreover, some question as to its advisability, for the amount of throttling which may safely be practised with a turbine is limited, as the latter must not be checked so that its critical speed be passed. In addition, the effect of the air-blast pressing up against the hot-gas valve during the "run" is desirable, in that, if the valve is not perfectly gastight, gas from the generator

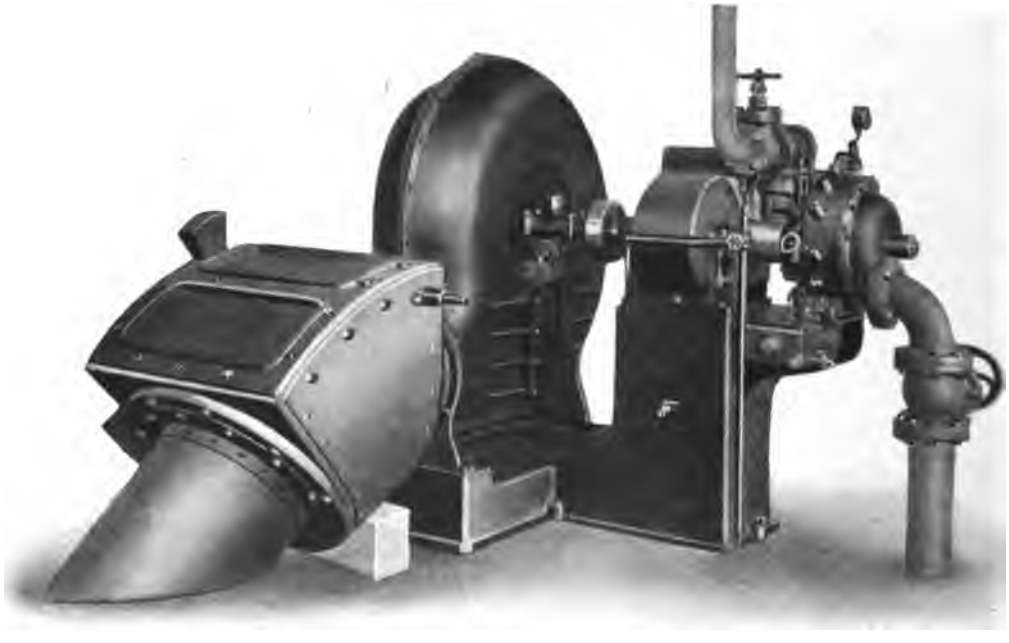


FIG. 332.—STEAM TURBINE BLOWING PLANT FITTED WITH AUTOMATIC SHUT-OFF.

will be prevented by the blast pressure (which is usually greater than the gas pressure in the generator) from leaking back into the blast main, although such an occurrence is unlikely with modern valves and interlocking gear.

PRACTICAL CONSIDERATIONS

In order to ensure the effectual and economical operation of a water-gas plant it is essential that frequent attention be given to what to many may be considered only minor features of the process. Exceptional results, however, as in the manufacture of coal gas, are obtained by observing the utmost care in connexion with details rather than by concentrating upon the more apparent items. The following may be considered amongst the chief factors influencing working efficiency :—

(1) *The Fuel Bed.* In the single generator plant (as opposed to the twin variety) it is generally laid down as a golden working rule that the depth of the fuel bed must always be maintained. If a shallow fuel bed is employed it cannot be disputed that the reduction of CO_2 to CO will not take place to the same extent ; hence the final product will contain a greater proportion of the former gas. At the present day, however, the presence of a small extra quantity of CO_2 is more or less immaterial, and the author has no hesitation in recommending an average fuel depth of about 6 feet 6 inches. By working at this level the period of blowing may be curtailed (with a corresponding gain in available gasmaking time), and the capacity of the setting will be appreciably increased. The additional amount of gas obtained will have an important effect in reducing cost of manufacture. If this depth of fuel is employed the coke should be moderately small, nothing greater than 3-inch pieces being employed. If a particularly heavy coke is made use of, less of it will be required as compared with the normal gasworks variety, therefore there need be no hesitation in reducing the fuel depth. The purity of the coke is an important factor, a high percentage of ash causing the clinker to arch over and hang up. The most effective remedy for troubles of the kind is to arrange for a system of periodical " down runs." In this way the clinker is driven down towards the grate bars and will form in larger pieces, which may be more readily dealt with than can a number of small isolated lumps. A " down run " should be arranged for after every three or four runs in the upward direction ; but it is as well to admit no top steam for at least an hour before clinkering takes place. As regards purity of the material, it may be noted that retort carbon makes an admirable fuel for water gas manufacture, entirely obviating the tedious process of clinkering ; but its commercial value and the small quantities in which it is produced on gasworks preclude the possibility of its use. It must be remembered that the fuel bed and the fireclay walls of the generator are the stores of heat, and the heat retained by them only is available for the reactions. Temperatures must therefore be maintained, the generator being worked up to at least 2,000° Fahr. before the " run " is commenced. By the time the run is completed the temperature will have dropped some 300° to 500° Fahr. The effect of this is shown by the manner in which the make of gas falls off towards the end of the run, with a gradual increase in the CO_2 content. Stelfox, experimenting with seven-minute and eight-minute " runs," found the following results :—

	Seven-Minute "Run."	Eight-Minute "Run."
Gas made during 1st minute	1,882 cubic feet	1,840 cubic feet
„ „ 2nd „	1,554 „	1,595 „
„ „ 3rd „	1,472 „	1,513 „
„ „ 4th „	1,472 „	1,308 „
„ „ 5th „	1,144 „	1,103 „
„ „ 6th „	982 „	941 „
„ „ 7th „	492 „	410 „
„ „ 8th „		410 „
Total	8,998 „	9,120 „

As regards the rate of increase of the CO_2 content the author finds that, working under the conditions of a comparatively shallow fuel bed as suggested above, the following may be taken as an average example with a six-minute "run":—

Generator Gas.

	Percentage of CO_2.	Percentage of CO.
End of 1st minute	2·2	46·3
„ 2nd „	3·6	42·0
„ 3rd „	4·3	40·1
„ 4th „	5·8	33·6
„ 5th „	7·9	31·9
„ 6th „	9·4	28·4

The policy of superheating the steam before its admission to the generator is one on which much discussion has taken place. Certainly, by this means a greater store of heat is ensured in the generator, and superheating is provided for in the Dellwik and some "K. & A." plants. If the practice can be carried out without introducing structural complications, and by making use of heat which would otherwise be wasted, it is, no doubt, to be commended. But in any case the effect will be limited. Glasgow has pointed out that even when superheated to 1,500° Fahr. the steam carries scarcely 9,000 additional heat units, or but 2½ per cent. of the energy absorbed in the manufacture of the carburetted product. The provision of a dry steam is, however, essential; and to this end the boilers should be adjacent to the plant, the steam mains being adequately lagged, and, if necessary, trapped. Sufficient and uniform boiler pressure is essential, for if the steam pressure is permitted to fluctuate to any marked extent it will be followed by disastrous results on the output of the plant. Many installations are designed to operate with steam at 130 lb. per square inch, though 100 lb. pressure is, perhaps, more common. In the latter case, some appreciable improvement will frequently be followed by increasing

the pressure to 110 lb., if the boilers are capable of taking the increase. Steam meters are an undoubted asset to any plant, and enable accurate adjustment to be made. The factor of the quantity of steam admitted is of greater importance than might at first sight be supposed. Whilst a sufficiency of steam is imperative, an excess is to be rigidly avoided. If too great a quantity is admitted the surplus steam passing through the fuel bed may actually account for a reduction in the quantity of CO, with a corresponding increase in CO_2, thus :—

$$H_2O + CO = CO_2 + H_2.$$

—a reaction which may occur tolerably easily at present-day generator temperatures of 2,000° Fahr. In general, it will be found that for effective results the consumption of steam will amount to from 27 to 30 lb. per 1,000 cubic feet of gas. Thus, with

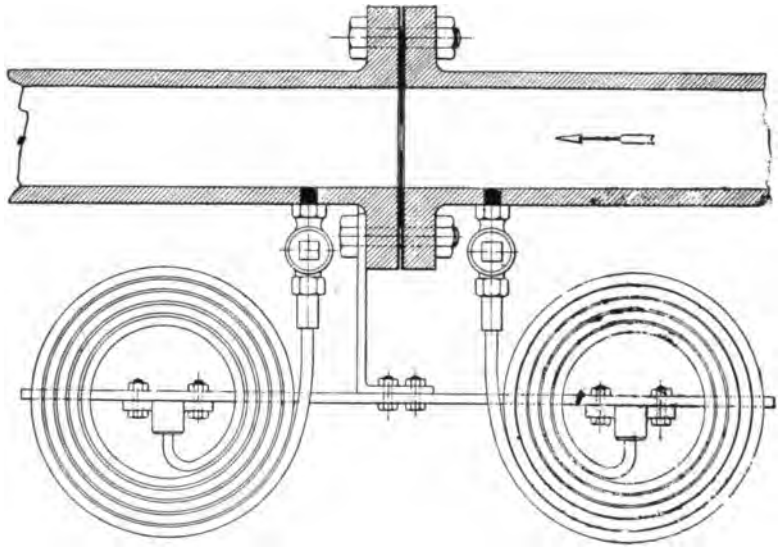


FIG. 333.—DIAGRAM SHOWING PRINCIPLE OF STEAM METER.

a plant making 8,000 cubic feet per run of five minutes the steam should be set at a rate of about 45 lb. per minute. It will be found that the " down run " supply can be adjusted to give a rather greater flow than the up steam, roughly about 2 lb. per minute more.

Steam meters, as used on water-gas plants, are calibrated to read pounds of steam passing per minute. There are many types, most of which are constructed to read direct on a dial, or to give an autographic record. Kent's steam meter (Fig. 333) is based upon the principle that steam flowing through a constriction in a pipe falls in pressure, the pressure drop being approximately proportional to the square of the velocity of flow. The constriction consists of an orifice plate which is bolted between two flanges, the size of the orifice being such that the desired pressure drop at the maximum discharge is obtained. The pressures from the inlet

and outlet sides of the orifice are conveyed through copper pipes to the two portions of the diaphragm, the movement of which corresponds to the differential pressure created by the steam flow. The diaphragm movement is then transmitted through a gland to the indicating mechanism. The loss of pressure due to the insertion of the orifice amounts to about ¾ lb. per square inch at maximum flow.

(2) *The Blow.* The direction of the blast is always upward, no reversal being possible as in the case of the steam. The pressure of the air as delivered from the fan usually varies between 17 inches and 22 inches of water, but much depends upon the type and size of the plant and the fan capacity available. It must be borne in mind, however, that the blast must under all circumstances provide an excess of air, otherwise the extent to which combustion to CO_2 takes place will be limited, with the result that less heat is dispersed. It will be remembered, in this connexion, that the partial combustion of coke to CO accounts for only one-third of the heat derived from complete combustion (*see* page 48).

As is to be expected, the construction of blowing fans has undergone some considerable modification since the introduction of water gas.

Some twenty or more years ago, when the manufacture of water gas was in its infancy, a blast pressure of from 8-inch to 15-inch water-gauge was considered suitable for the generators, and any good blowing fan would do the work.

A few years later the output of gas plants was largely increased by running the fans at greater pressures, and, as the speeds required for the new conditions were too high for the fans then in use, the results in many cases were disastrous. In order to meet the conditions a special extra heavy fan was then introduced. This new type of fan, made exclusively for water-gas purposes, is capable of supplying air at a pressure of from 15-inch to 25-inch water-gauge, or even greater pressures if necessary.

Bearing in mind the very important duty performed by the blowing fan in the manufacture of water gas, it cannot be emphasized too strongly that, in order to eliminate as far as possible all risk of breakdown, the blowing apparatus should be specially designed and suitable for long runs with a minimum of attention.

The following table gives the approximate size of fan (Sturtevant type) required for a given size of water-gas plant :—

Standard Size of Fan.	Capacity of Water-Gas Plant. Cubic feet per diem.	B.H.P. absorbed by Fan.	Speed of Fan. Revs. per minute.
4	150,000	10·25	3,400
5	200,000	14·50	2,920
6	300,000	15·50	2,475
7	500,000	23·50	2,175
8	650,000	32	1,625
9	850,000	44	1,425
10	1,000,000	58	1,225

In view of the fact that fans operating in conjunction with water-gas plants

have to work intermittently, it would not seem advisable to employ blowers of the positive type. For instance, when no blast is required a positive blower must be stopped altogether, or a valve must be fitted on the blast main to release the air when the pressure rises above a pre-determined figure. The latter, however, is a somewhat wasteful proposition. With this type of blower, moreover, the questions of wear and tear and noise during working have to be considered. With a centrifugal fan it is possible to regulate the delivery of air by a valve placed in the blast main, the speed of the fan being kept constant. As the valve is closed or opened, less or more air is allowed to pass to the generator, and the power absorbed by the fan rises or falls according to whether the valve is opened or closed.

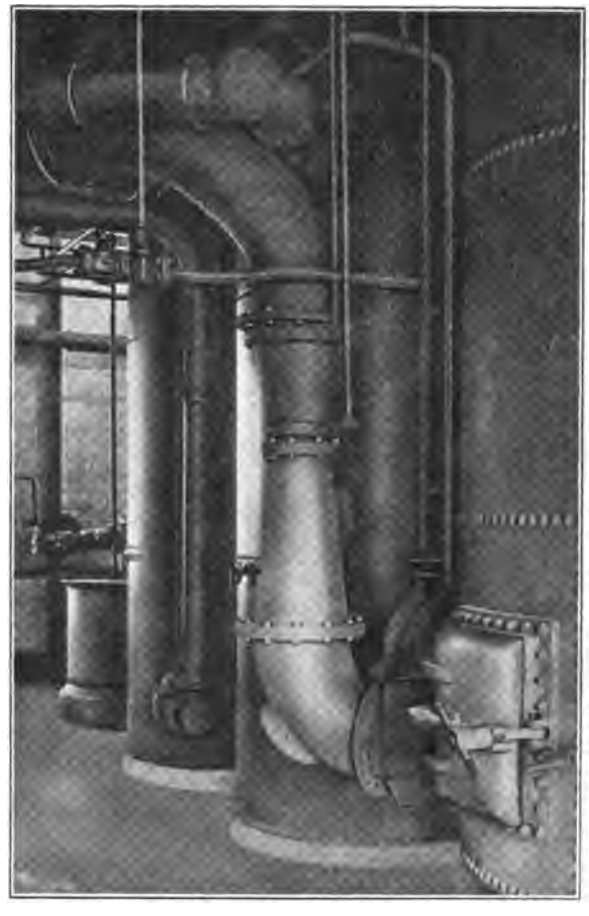


FIG. 334.—AIR METER ATTACHED TO GENERATOR BLAST MAIN.

(3) *Amount of Air required.* The amount of air which should be required during the period of the "blow" is most readily gauged upon the gas-producing capacity of the plant. As a general rule it may be taken that the quantity of air should not exceed from 2,000 to 2,500 cubic feet per 1,000 cubic feet of gas made. Thus, with a medium-sized plant, making 8,000 cubic feet during a five-minutes' "run," the total air passed should lie between 4,000 and 5,000 cubic feet per minute. It has been previously pointed out that as the "blow" proceeds, so does the proportion of carbon monoxide in the producer gas increase. For this reason it has been suggested that the fan should be gradually speeded up so that a greater volume of air is passed towards the end of the "blow." The practice has, as a matter of fact, been tried, but general experience has gone to show that the benefits are not commensurate with the additional complications entailed. A more satisfactory arrangement, from the practical point of view, is that of gradually increasing the

secondary air to the carburettor and superheater during the "blow." This can be conveniently done in a hydraulically operated plant such as that at the Beckton works. Air meters fitted to the blast main are more or less a luxury, but are occasionally found. Fig. 334 shows an air meter of the Venturi type.

The satisfactory regulation of the blast is a considerable factor in water-gas operation, for it must be remembered that very much more fuel may be consumed during the "blow" than is actually made use of for gasmaking. With extravagantly operated plants, in which the blast may be excessive, the fuel burnt during the "blow" may amount to three or even four times the quantity disposed of during the "run." A. G. Glasgow in a test with a plant consuming hard coal found that, working under favourable conditions, the consumption of carbon during "blow" and "run" was as 13·88 to 9·62, or, about 60 per cent. was accounted for during the "blow," and 40 per cent. was used for gasmaking.

For effective results it is essential that local blowing, or imperfect distribution of the air blast and the steam supply, should be avoided. For this reason the fuel supplied to the generator should be as uniform in size as possible. If clinkering is imperfectly carried out and large lumps are allowed to form and remain lodged up in the generator effective distribution is impossible. Thus the air blast will find its way through certain portions only of the bed, which portions will be raised to an abnormally high temperature, whilst the remainder of the bed is in a condition of comparative coolness. Local steaming of the bed may, in the same way, be due to the formation of clinker, although it frequently occurs from the steam supply nozzle being non-central, partly choked, or broken.

Owing to the gradual reduction in temperature of the fuel bed during the "run" it has been suggested that the steam supply should undergo reduction as the period of gasmaking proceeds. In this way a rather better quality gas will be obtained, but the capacity of the plant is to a certain extent curtailed. The gradual diminution of the steam is, therefore, the exception rather than the rule.

(4) *Periods of "Run" and "Blow."* The duration of the "run" and "blow" differs in accordance with the type of plant. The following show the average conditions of working:—

	"Run."	"Blow."
Lowe Plant	5 minutes and	3 minutes.
or	6 minutes and	4 minutes.
"K. & A." Plant	5 minutes and	70 seconds.
Dellwik Plant	6 minutes and	60 seconds.

With the standard type of carburetting plant the author has found that the most favourable results are obtained by working on the five-minutes' "run" and three-minutes' "blow" cycle, but that the "run" immediately prior to recharging the generator may be prolonged to six minutes. At such stages the fire is shallow and exceedingly hot, and there appears to be a good yield of gas during the extra minute. After coking up, moreover, it is as well to prolong the "blow" to four minutes.

Clinkering on water-gas plants must be carried out at frequent intervals, for

if once the mass is allowed to grow it will gradually arch over in the generator until the latter is almost completely choked. With the Lowe plants it is advisable to perform the operation at intervals of four hours, although in cases where a good quality coke is procurable the period may be prolonged to six hours. In many of the " blue " gas plants with double generators clinkering takes place only once in ten or twelve hours. In recent years mechanical grates, which obviate the greater portion of the labour entailed in clinkering, have been introduced, but they are as yet confined to generators of the larger capacities. Briefly, they consist of specially designed firebars which are caused to rotate and scrape out both clinker and ashes. A generator fitted with such a grate, designed by Humphreys and Glasgow, is seen

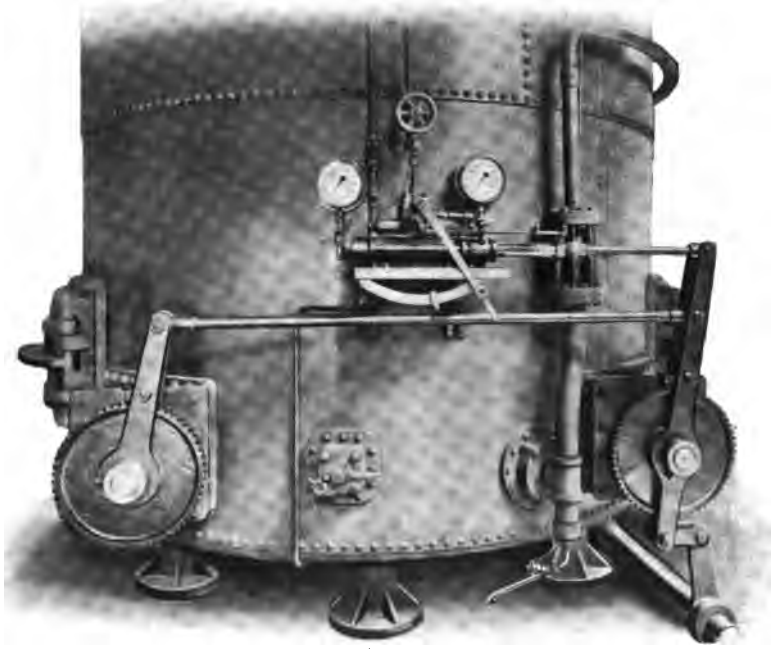


FIG. 335.—GENERATOR FITTED WITH AUTOMATIC CLINKERING DEVICE.

in Fig. 335. The Kerpely producer, which is built with a specially revolving ash-extracting grate, has already been referred to in Chapter III (*see* page 81).

(5) *Carburation.* In the original plants employed for the manufacture of carburetted water gas it was usual to spray the oil direct on to the fuel in the generator. This procedure, however, proved decidedly wasteful, with the result that a separate vessel was soon introduced for purposes of carburation. The duty obtained from the carburetting medium employed will largely depend upon the manner in which the vessel is operated and maintained, whilst temperature is a factor of considerable importance. The main consideration to bear in mind is that the heat must be suffi-

cient to crack up the oil into vapours which will as far as possible be retained as permanent gases, but it must not be so great as to cause such degradation as gives rise to over-cracking and the deposition of free carbon. Frequently, it is stated that a desirable working temperature for both carburettor and superheater is 1,700° Fahr., or thereabouts. The author finds, however, that for high results in the direction of "candles per gallon" the American oil as now almost universally used is preferably decomposed at lower temperatures. Moreover, it will be found advantageous to work the superheater at slightly higher temperatures than the carburettor. The temperatures suggested when under normal working conditions are :—

Carburettor	between 1,350° and 1,400° Fahr.
Superheater	„ 1,400° and 1,450° „

This, however, must not be considered as a hard-and-fast rule, for very much depends upon the quantity of oil being injected during the "run." For instance, if a poorer quality gas is being manufactured, and only about half the normal quantity of oil is in use, the temperature must be regulated in accordance. Another factor is the time taken to inject the oil. The quantity sprayed in must not be so apportioned that oil is running in during the whole of the gasmaking period. Such procedure would lead to inevitable waste, for the carburettor and superheater would not be swept clean from oily matter before the commencement of the "blow." Generally, it may be said that it is as well to arrange for the desired quantity of oil to be sprayed in during the first half of the "run" or thereabouts. For instance, with a five-minutes' "run" the oil may be got rid of in the first three minutes, leaving two minutes for the manufacture of "blue" gas, which will perform the necessary scavenging of the remaining vessels. The oil spray is a matter of importance, and thorough atomization should be aimed at. It would seem that rather than the oil should be injected under a pressure of 40 lb. per square inch it is preferable to employ higher pressures of from 80 to 100 lb. Such pressure in conjunction with a spray of the Brighton type (Fig. 336) gives the most effective mechanical subdivision and uniform distribution. The extremely fine distribution of the oil in this manner tends towards maintaining the chequer-work of the carburettor in a more cleanly condition, whilst patchiness in heating is avoided. It is customary on gasworks in arriving at an indication of the efficiency obtained from the oil to note from day to day the yield of "candles per gallon." This figure is arrived at by taking the average candle power of the gas and dividing it by the oil used per 1,000 cubic feet of gas made over the same period. In practice the result varies between 7 and 8 candles per gallon, but the latter figure should be easily obtainable when the set is worked on effective lines. It may be stated here that the amount of gas yielded per gallon of American gas oil varies from 70 to 90 cubic feet.

A rough-and-ready test which may be applied to the superheater in order to determine whether the most is being made of the oil is merely that of holding, during the "run," a piece of clean blotting paper to a small jet of the gas taken off from the down pipe from the superheater. If the oil is being subjected to too great a heat a small black deposit of free carbon will be found on the paper; if, on the other hand, it is insufficiently cracked, a slight deposit of an oily nature will result. In

the majority of carburetting plants a device is in use whereby the oil, before being passed into the carburettor, is preheated by the hot gas leaving the plant. The heater is usually placed in the down pipe leading from the superheater, and raises the temperature of the oil to about 230° Fahr. In this way the "candles per gallon" are appreciably enhanced; but the author would point out that in some instances he has found that the removal of the oil heater has been followed by a general improvement in results. This fact is ascribed to the reason that the heater appropriates a considerable portion of the area of the main gas outlet, with the result that the latter is insufficiently large for the gas to get away with the ease it

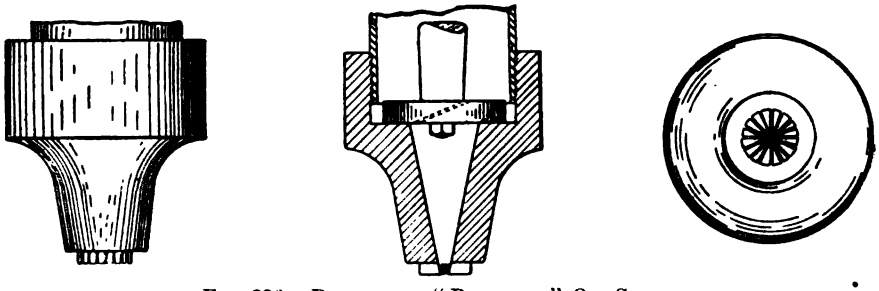


FIG. 336.—DETAILS OF "BRIGHTON" OIL SPRAY.

should do. A point which is patent to all users of water-gas plant is the necessity for scavenging the apparatus prior to commencing the "blow." When the steam is shut off at the end of the "run" the vessels, the cubic capacity of which is fairly considerable, remain full of water gas. To open the stack valve at once and to commence with the "blow" would be to discharge this water gas into the air. To preclude this, after the steam is shut off the stack valve should remain closed, not being opened until the air blast has been passing through for a few seconds. In this way, the gas will be driven forward to the holder, and the plant will be effectively cleared out.

MATERIALS USED

The materials used for the manufacture of carburetted water gas vary, as regards quantity, between the following limits:—

Coke . . .	32 to 41 lb. per 1,000 cubic feet of gas.
Oil . . .	about 2¼ gallons per 1,000 cubic feet of 18 candle power gas.
Steam . . .	27 to 30 lb. per 1,000 cubic feet of gas.

A figure of 35 lb. for coke consumption is probably the most favourable obtained with plants of the Lowe type, but some reduction on this may be expected in those cases where the pan coke is extracted from the generator refuse and deducted from the total weight of coke shot into the generator. Plants designed essentially for the production of "blue" gas are generally able to economize in the direction of fuel, and figures so low as 25 lb. of coke per 1,000 cubic feet have been obtained. As an average, however, the quantity will vary between 30 and 34 lb. These figures, as in the case of those given for carburetting plants, are exclusive of the fuel required

in the boilers for steam raising. The steam-raising plant will, with the mixture of breeze and coke usually employed on gasworks, require an additional 12 to 15 lb. of fuel per 1,000 cubic feet of gas made.

The cost of manufacture of water gas must depend largely upon the current market values of the raw products, coke and oil, the latter accounting for from 50 to 65 per cent. of the whole. For this reason it will be seen that the manufacture of "blue" gas is a very much less costly undertaking than is the case with a carburetted gas. In general, the following statement will conform to normal conditions :—

18 CANDLE POWER CARBURETTED GAS.

Coke for generators			4*d.*	per 1,000 cubic feet of gas.
Coke for steam raising			1½*d.*	„ „ „
Oil, 2¼ gallons at 4*d.*			9*d.*	„ „ „
Wages			1½*d.*	„ „ „
Wear and Tear			1*d.*	„ „ „
			1*s.* 5*d.*	„ „ „
Less Residuals—				
Tar		0·6*d.*		
Pan coke		0·07*d.*		
Sulphur		0·03*d.*		
		0·7*d.*		

Net cost 1*s.* 4·3*d.* per 1,000 cubic feet.

The above represents the case for a medium-sized plant. It will, of course, be quite evident that as the size of the unit increases so do the various individual items undergo reduction, for the gas-producing capacity of the attendant and general working efficiency are enhanced *pro rata*. The above example illustrates in a marked degree the influence of the current value of oil on the cost of the gas. At one time oil could be obtained for somewhat less than 2*d.* per gallon, but the extent to which it is likely to fluctuate is emphasized by the fact that during the European war large consumers were obliged to pay nearly 10*d.* As regards capital cost, much again depends on the size of the installation; but in normal times it may be assumed for a complete plant of the Lowe type, including housing, boilers, exhausters, purifiers, relief holder, etc., to lie between £20 and £25 per 1,000 cubic feet of capacity. The approximate cost of the various portions of the apparatus is exemplified in the instance given in Chapter I, page 25.

THE COMPOSITION OF WATER GAS

With the exception of the diluents nitrogen and carbon dioxide, straight or "blue" water gas consists almost solely of hydrogen and carbon monoxide. A small percentage of methane is usually, but not necessarily, present. The final composition of carburetted water gas necessarily depends to a large extent upon the proportion of oil used in its manufacture. Under any circumstances, the constituents differ to some considerable extent from those of coal gas. As regards hydrocarbons,

those of the unsaturated variety absorbed by bromine will be present to the extent of about 10 per cent. in a gas of 18 candle power. The same quality gas will also contain about 13 per cent. of paraffins, the greater portion of which will consist of methane. The unsaturated hydrocarbons, with present-day heats, consist largely of the benzene series.

As regards the mixture of coal gas and carburetted water gas as supplied to consumers, with the usual proportion of carburetted gas, that is from 25 to 30 per cent. by volume, having an illuminating power of from 17 to 18 candles, and admixed with coal gas of from 13 to 13½ candles, the composition of the mixture will approach the following :—

COMPOSITION OF MIXED GAS, ABOUT 14½ CANDLE POWER.

Hydrogen	44·0	per cent. by	volume.
Methane	22·0	„	„
Unsaturated hydrocarbons	5·8	„	„
Carbon monoxide	16·5	„	„
Carbon dioxide	3·5	„	„
Nitrogen	8·2	„	„

In addition to the above there might be found an amount of oxygen varying from traces to 0·2 per cent.

When used for the purpose of enriching a coal gas of low quality, carburetted water gas appears to possess the property of enhancing the illuminating power of the mixture to a greater extent than is shown by theoretical reckoning. For instance, if 75 per cent. of the mixture consists of coal gas of 13 candles and 25 per cent. is made up from water gas of 18 candles, the final candle power obtained should, by computation, be 14·25. In practice, however, the actual candle power of the mixture will be in the neighbourhood of 15 candles, thus showing the additional enriching effect obtained. The explanation, no doubt, is one of flame temperature, water gas burning with a smaller flame than coal gas ; and, when admixed with the latter, the carbon particles of the coal gas are raised to a higher degree of luminosity than when the coal gas is burned by itself.

The impurities in water gas consist of sulphuretted hydrogen and carbon disulphide. The gas is generally free from ammonia, but occasional traces of this may be found. The proportions in which the impurities are present are approximately as follows :—

Sulphuretted hydrogen	110 to 120 grains per 100 cubic feet, or about 0·2 per cent. by volume.
Carbon disulphide and other sulphur compounds	10 to 15 grains per 100 cubic feet.

The specific gravity of water gas is higher than that of coal gas, the gravity of the carburetted gas being in the neighbourhood of 0·65 as against an average figure of 0·47 for coal gas.

The manner in which the specific gravity of water gas increases with the candle power is shown by the following results obtained by F. H. Shelton :—

Candle Power.	Specific Gravity (Air=1).
19·5	0·571
20·0	0·630
22·5	0·589
24·0	0·60 to 0·67
25·4	0·64
26·3	0·602
28·3	0·70
29·6	0·65
30 to 31·9	0·65 to 0·71

COMPOSITION OF VARIOUS GASES

	Coal Gas.	Carburetted Water Gas.	"Blue" Water Gas.	Mond Gas	Suction Gas.	Dowson Gas.
	Per cent.	Per cent.				
Hydrogen	49	35·0	52·0	26·0	16·0	20·0
Carbon monoxide	9	32·0	38·0	15·0	34·0	24·0
Carbon dioxide	3·5	4·5	4·5	12·0	3·0	6·0
Methane	27·0	13·0	1·0	3·0	nil	1·0
Heavy hydrocarbons (CnHm).	4·0	10·0	nil	nil	nil	nil
Nitrogen	7·5	5·5	4·5	44·0	47·0	49·0
Candle power	14·0	18	nil	nil	nil	nil
Calorific power gross. B.Th.U. per cubic foot	550	580	300	165	160	155

WATER-GAS TAR

The quantity of tar thrown down during the scrubbing and condensation of carburetted water gas will amount to from 12 to 16 gallons per 100 gallons of oil gasified. This tar is, unfortunately, a frequent source of trouble in two directions. First, the lighter tarry vesicles which are difficult to remove from the gas in the preliminary stages remain suspended therein and are eventually extracted as the gas passes through the oxide purifiers. The tar, being deposited on the oxide, not only reduces its activity and gives rise to excessive back-pressure, but it renders the spent material of little commercial value. Many mechanical devices have been employed with a view to removing the suspended particles of tar before the gas arrives at the dry purification plant. One of the most successful of these is the "Hurricane" trap shown in Fig. 337, which is fitted in a vertical main where the flow of gas is downwards. The apparatus consists of a cone A, having its apex against the flow of gas and its base formed into a ring plate B about 6 inches in depth. An annular space is formed around the ring plate by fixing a second ring, C, mounted on a foundation plate, D, the other end of which, E, forms another ring. A second cone, F, is suspended below the upper one, the diameter of this cone being some 3 inches less than that of the main. The gas to be treated is obliged to pass through the narrow annular space, where it is wire-drawn, the vesicles being made to agglomerate and form a rain. The gas is then deflected upwards on to the

underside of the top cone, which again deflects it downwards on to the top of the lower cone. This lower cone receives the deposit of tar rain, which trickles from the edges and runs away to the seal.

There is no doubt that wire-drawing, if effectively carried out, can be used successfully for the removal of tarry vesicles. It would appear, however, that the principle of bubbling as embodied in washers of the Livesey type is difficult to improve upon. A washer of this description (into which a small stream of liquor from the water gas scrubber is constantly permitted to run), fitted prior to the carburetted water-gas purifiers, will usually eliminate almost the whole of the suspended particles in the gas. It must not be forgotten, moreover, that efficient condensation is an important item in this respect, and if the gas is permitted to leave the condensers at an abnormally high temperature, trouble is only to be expected.

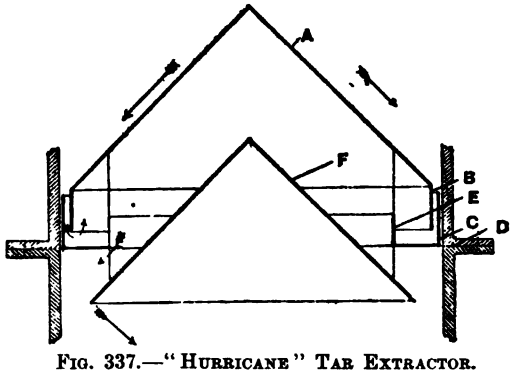


FIG. 337.—"HURRICANE" TAR EXTRACTOR.

In the second direction water-gas tar is in many cases an annoyance in that, being of practically the same specific gravity as water, it admixes with the latter and forms an emulsion of a very permanent character. The consequence is that the tar as made ready for sale may contain so much as 40 per cent. of water. Various means, including centrifugal treatment, heating, etc., have been experimented with for the purpose of effecting separation, but the matter still remains something of a problem.

As regards the composition of tar from the manufacture of carburetted water gas, S. Carter has given the following analysis :—

Specific gravity, 1·0665.

Benzol, 90 per cent.	1·11 per cent.
Naphtha.	2·33 „
Creosote oil	21·35 „
Naphthalene	4·09 „
Anthracene oil	15·91 „
Pitch	56·70 „

For the same type of tar Matthews and Goulden give the following figures :—

Benzene	1·19 per cent.
Toluene	0·83 „
Paraffins.	8·51 „
Solvent naphthas	17·96 „
Phenols	Trace
Middle oils	29·14 „
Creosote oils	24·26 „
Naphthalene	1·28 „
Anthracene	0·93 „
Coke	9·80 „

WATER-GAS ENRICHING OIL

In the early days of carburetted water gas in this country the enriching medium employed was almost solely a Russian Solar distillate. At the present day, however, the centre of supply has moved to America, from which country the residual petroleum, having a specific gravity of about 0·85, is obtained in large quantities. The gas engineer, so long as he can obtain his oil for a reasonable price, does not trouble very much about its quality, although an inferior product will soon make its mark on the working results of the plant.

It has been more or less conclusively proved that the laboratory analysis of gas oil is of little avail in determining the suitability of the oil for carburetting purposes. On this account it is unusual to subject consignments of the oil to anything more than the crudest tests.

It is general for the gasworks' chemist to draw off his sample carefully and to note the specific gravity of the oil; but the result affords him no indication of the gasmaking qualities, and is merely a guide as to the origin, upon which this property to a large extent depends. So far as the origin of gas oil is concerned, it has already been pointed out that practically all of that imported now comes from America. The other suitable types, Russian Solar distillate, also Galician—these being high-grade oils—have not been imported for some years. Rumanian oils are of a poorer character and rarely reach this country.

With regard to gasworks' tests, the only true indication of the suitability of an oil is a practical trial run by an engineer who knows the ins and outs of the working of his plants. Oils have frequently been known to give satisfactory laboratory tests in every way, and yet to yield unsatisfactory results. Petroleum, being a natural product, is liable to considerable variation, and no agents for gas oil will guarantee results or "candles per gallon." For American oils the specific gravity should fall between 0·845 and 0·865. The test for flash point is important, owing to the fact that if this falls below 73° Fahr. a special licence for storing is required, while higher rates will be demanded for railway carriage. The test may best be carried out by means of the Abel "closed" apparatus, and affords a fair indication as to the percentage of volatile constituents. The details of the test need not be described here, and it will be sufficient to recall that the flash-point of an oil is the temperature at which it gives off sufficient vapour to ignite momentarily on the introduction of a spark or flame. The oil is heated at a prescribed rate, and a definite ignition agent is applied in a given manner.

One of the most satisfactory methods of testing a gas oil destined for water-gas manufacture is to ascertain by fractional distillation whether or not it is of a homogeneous nature; that is to say, not merely a mechanical mixture of different oils likely to separate out when stored in a tank. A suitable homogeneous oil would give fractions coming away with fair regularity between the second and eighth or ninth 10 per cent. periods. The proportion of the oil distilling over at a temperature of less than 600° Fahr. should also be noted; this should be as low as possible, for the reason that a high yield of these fractions indicates a tendency towards undue

volatility. More than 10 per cent. remaining at 750° Fahr. would show the presence of undesirably heavy constituents; while the specific gravity of the various fractions should show a fairly uniform progressive rise. Uneven jumps at various temperatures are not a recommendation.

The Standard Test

The solid residue remaining after the completion of fractionation is of no little importance, and should never exceed 2 per cent. by weight of the original quantity of oil taken; in many cases the figure will be found to be below 1 per cent. Mexican oil will usually leave a far greater solid residue, occasionally amounting to more than 5 per cent.

The standard test for oil which is carried out at many of the larger gasworks is to distil 10 fluid ounces in a special apparatus, and to carry the temperature up to 660° Fahr., this latter point being gradually arrived at in a period of 40 minutes. The residue remaining behind is then cooled, and its specific gravity noted. If the oil is of a desirable quality the gravity will be 0·900. Probably one of the most important items is the sulphur content, and this should not be allowed to exceed 0·4 to 0·5 per cent. The quantity of water is also to be watched, and may be conveniently estimated by use of a "Sutherland bulb." The rougher test for all oils which lose an inappreciable percentage of hydrocarbons on being heated to 230° Fahr. is to weigh 25 grammes in a glass dish, heating to this temperature on a sand bath, and continually stirring until bubbles of steam cease to form. The sample is then allowed to cool, and is re-weighed, when the loss of weight in grammes, multiplied by four, represents the percentage of water present.

Although of considerable importance, owing to its effect on the sulphur impurities of the gas, the test for sulphur is seldom carried out on gasworks. A convenient method of obtaining an idea as to the quantity of sulphuretted hydrogen is to hold at intervals a piece of moistened lead acetate paper above the outlet of the condenser; if sulphuretted hydrogen is present the paper will be blackened in the usual manner, the degree of blackening giving a fair indication of the amount of sulphur in the oil. The total sulphur present can conveniently be arrived at by Carius's method, or by the use of the bomb calorimeter; but for gasworks' purposes a ready means would be that of taking a weighed quantity of oil, mixing it with a spirit (such as alcohol) entirely free from sulphur, and then burning it in a suitable lamp. The products are collected in an apparatus similar to that prescribed by the metropolitan gas referees for testing sulphur compounds. Other refinements of oil testing include the use of the calorimeter and tintometer. But such apparatus is usually beyond the scope of the average gasworks.

THE THERMAL EFFICIENCY OF A WATER-GAS PLANT

By means of a series of experiments carried out in America, A. G. Glasgow has calculated the actual heat efficiency of a carburetted water-gas plant. Although his research was undertaken some twenty-five years ago the results have not as yet been challenged or supplemented by others. In this case the water-gas plant was

operated with anthracite, and not coke, and it was first necessary to ascertain the weights, temperatures, composition, etc., of the raw materials and finished products. With regard to some of the data obtained the following list of temperatures will prove interesting to all makers of water gas :—

Gas issuing from superheater	1,450° Fahr.
Blast gases issuing from superheater	1,550° „
Oil leaving preheater	235° „
Blast entering generator	76° „
Steam „ „	331° „
Ash, etc., withdrawn from generator	1,560° „

The heat absorbed by the apparatus is represented, on a basis of 1,000 cubic feet of the carburetted gas, first by the amount of fuel fed into the generator. This was found to be 23·5 lb. per 1,000 cubic feet, after deducting unconsumed anthracite found with the ash. Secondly, there is the total heat entering with the steam; and, thirdly, the sensible heat entering with the blast. The various sources in which this heat is dispersed are shown in the following table :—

DISTRIBUTION OF ENERGY PER 1,000 CUBIC FEET

	B.Th.U.	Equivalent in Pounds of Carbon.
A, heat of combustion of carbon	340,750	23·5
B, total heat in entering steam	18,359	1·266
C, sensible heat in entering blast	715	·049
Total heat above 60° Fahr. fed into apparatus on fuel account	359,824	24·815
D, energy of CO in water gas	90,591	6·248
E, energy of H in water gas	108,908	7·511
F, sensible heat in escaping illuminating gas, vapours, etc.	35,583	2·454
G, sensible heat in escaping blast products	70,838	4·885
H, heat lost by radiation from shells	12,454	·859
J, heat carried away from shells by convection	15,696	1·083
K, heat rendered latent in gasification of oil	21,393	1·475
L, sensible heat in ash and unconsumed coal recovered	3,712	·256
Total energy accounted for	359,175	24·771
Unaccounted for (·18 per cent.)	649	·044

The final profit and loss account is, therefore, as follows :—

	B.Th.U.	Lbs.
Energy utilized	220,892	15·234
„ wasted	138,283	9·537
„ unaccounted for	649	0·044
Total	359,824	24·815

Assuming the unaccounted-for energy to be wasted, this leaves a heat efficiency of 61·4 per cent.

If the oil fed into the plant is taken into consideration as a further source of heat the result will be somewhat modified. In Glasgow's experiments 5 gallons of crude petroleum were admitted per 1,000 cubic feet of gas. The oil has a calorific power of approximately 18,500 B.Th.U. per lb., and 5 gallons would weigh 35 lb. Therefore :—

Heat entering with oil $= 35 \times 18{,}500 = 647{,}500$ B.Th.U. Adding this to the above, the total energy supplied

$= 359{,}824 + 647{,}500 = 1{,}007{,}324$ B.Th.U. per 1,000 cubic feet of gas.

The calorific power of the gas was found to be 720·987 B.Th.U. per cubic foot, and the quantity of tar recovered was 5 lb., its calorific value being assumed the same as that of the petroleum. Therefore, the heat recovered was :—

1,000 cubic feet of gas × 720·987	=	720,987 B.Th.U.
5 lb. of tar × 18,500	=	92,500 „
	Total	813,487 „

On this basis, the heat efficiency arrived at is equivalent to 80·76 per cent.

MODIFICATIONS OF WATER-GAS PLANT

During recent years there has been some tendency towards the modification of water-gas plant, with the result that in some instances apparatus of a novel character is to be found at work. One such instance is the plant for the production of what is technically known as "Methane-Hydrogen" gas, a semi-water gas enriched by means of coal gas tar.

Methane-hydrogen gas differs from ordinary water gas in many respects. It burns with a decided yellow, instead of a blue, flame, this being due to the high percentage of methane present, whilst the proportion of CO shows some considerable reduction as compared with "blue" gas. The approximate composition of methane-hydrogen gas is as follows :—

Methane	19 per cent.
Carbon monoxide	29 „
Carbon dioxide	3 „
Hydrogen	42 „
Unsaturated hydrocarbons	1 „
Nitrogen	5·8 „
Oxygen	0·2 „

In the plant for the manufacture of this type of gas the depth of fuel in the generator is nearly double that in the ordinary carburetted water-gas generator, but the lower portion only is raised to incandescence by the air blast admitted to the base. About mid-way up the generator the products of the "blow" are removed through special ports, thus maintaining the upper portion of the fuel bed at a moderate heat. During the "run" tar is injected as well as steam, the former being split up into carbon and methane. The carbon is filtered out by the cool upper portion of the bed, and gradually descends into the zone of combustion.

THE "DOUBLE-GAS" PLANT

One of the most interesting gasmaking plants erected quite recently at a few gasworks in this country is one which is designed to completely gasify both coal and coke in one operation. Thus, the coal-gas plant and water-gas installation—usually two distinct pieces of apparatus—are combined in one. The plant is generally known as Smith's modification of the "K. & A." patents.

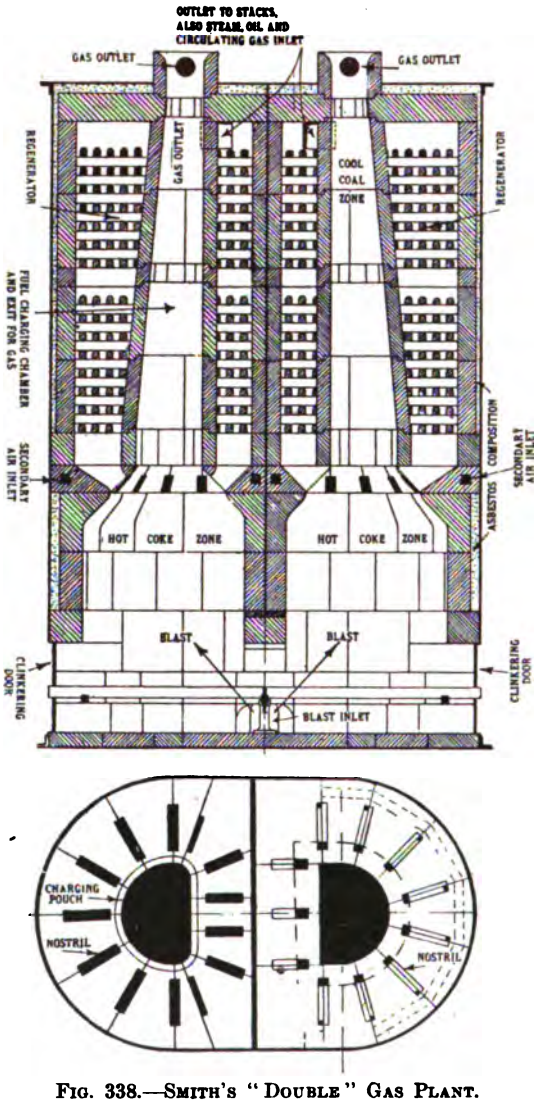


FIG. 338.—SMITH'S "DOUBLE" GAS PLANT.

In the original "K. & A." plant the system entails the use of two distinct generators, which are "run" through in series and "blown" through in parallel, thus complying with the necessity of arranging for a deep fuel bed during the "run" and a shallow fuel bed during the "blow." In the latest type (Fig. 338) of plant the same procedure is arranged for, but there is only one generating vessel, instead of the two, thus reducing capital outlay and minimizing heat losses. The outside shell, being of an oval cross-section, is divided into two parts by a plate suspended from the centre and reaching within a short distance of the base. The spaces on either side of this midfeather form the two generators, whilst room is also found for special compartments, known as "regenerators." It will be noticed from the sectional sketch that each generator is made up of two distinct portions, namely, the larger round coke receptacle at the base, whilst the upper tapered portion is D-shaped (not round) and forms, among other duties, a charging pouch for the coke or coal. It will be seen that at the upper end of the lower generator a series of "nostril" holes are arranged for. The grouping of these, together with the shape of the upper generators, can be best seen by referring to the sectional view.

The D-shaped portions of the generators are provided with an outlet at the top, whilst the regenerators have ports which serve the purpose of both inlets and outlets. A single blast inlet (the " blow," by the way, is a positive one) is provided midway between the two generators, between the fire-bars. The inlet, therefore, does duty for either generator.

As the plants so far erected have been primarily put down with the idea of making " blue " or uncarburetted water gas, the method of operating them for this purpose will be first described. Assuming that the generators, both upper and lower, are charged up and that the heats have been got up, a " blow " is first of all arranged for by admitting the blast through the inlet shown in the centre of the plant. This current of air then splits up into two streams and travels through both coke beds simultaneously as far as the nostrils. Owing to the valves at the top of the D-shaped generators being closed, the products of the " blow " cannot force an exit this way; hence they pass through the " nostrils," traverse the regenerators, and finally go out into the air by means of the stack valves. In this way the fuel in the generators is brought up to the desired temperature, whilst the products, in passing through the " regenerators," give up a further quantity of heat, so that the regenerators are maintained at a considerable temperature. The gases leaving the lower generators and passing through the nostrils contain, on an average, about 10 per cent. of carbon monoxide, and this is further burned to CO_2 by the admission of secondary air at the points shown in the sectional figure. The " blow " in this way usually continues for rather more than a minute. At the end of this time, the blast having been shut off and the stack valves closed, steam is admitted at the top of the regenerator on one side only. Passing downwards around the heated chequer work, it is partly split up and then travels first through one coke bed and finally through the second. In this way long contact with the fuel and thorough " reducing " is assured. Leaving the second fuel bed, the water gas already produced does not pass through the nostrils (the snift valve being closed), but forces its way through the cool core of fuel in the D-shaped pouch. It then passes into the special hydraulic main and, finally, through the scrubber. One of the chief advantages of passing the hot gas through the incoming coke in this way is that the greater part of the moisture is driven off from the fuel; and, moreover, the outgoing gas is thoroughly filtered.

In the cycle just described no mention has been made as to how carburation is effected. For this purpose air from a compressor is admitted to the surface of the oil in a storage receiver, when the oil is forced out at a pressure of from 30 to 40 lb. per square inch, through a special regulating spray and into the top of the regenerator. Each regenerator is fitted with such a spray, but the oil is only admitted to that one surrounding the top of the generator through which the gas is finally passing. The oil gas is accordingly forced downwards by its pressure, passes through the nostrils, and meets the upgoing stream of " blue " water gas. The two are then thoroughly intermixed during their passage through the cooler coke core.

With regard to the duration of " runs " and " blows," it is usual, after a

one-minute " blow," to admit steam for five minutes. After the following " blow " the direction of the steam is reversed.

When the plant is used for carbonizing coal and gasifying the resultant coke it is fitted with two automatic feed hoppers which are regulated to provide what practically amounts to a continuous charge. During the five-minutes' " run " the hot gas evolved from the lower portion of the bed passes up through the cooler zone and partly carbonizes the coal. The latter gradually works its way down the upper portion of the generator, undergoing more and more complete carbonization during its travel. In general, it is usually reduced to the state of ordinary coke by the time it has passed two-thirds the way down the D-shaped portions of the generator. Thus during the " run " water gas is being evolved from the coke and coal gas from the coal, the two intermixing and passing out at the top of the generator. In this way, by the complete gasification of both coal and coke, about 60,000 cubic feet of gas having a calorific power of 380 B.Th.U. per cubic foot may be obtained from a ton of coal.

THE RINCKER-WOLTER PLANT

The system known as the Rincker-Wolter has been working for some years at the Utrecht gasworks, and the plant seems to have proved itself an effective and economical adjunct to the coal-gas apparatus. Its chief dissimilarity from other plants lies in the fact that waste oil, however dirty or inferior, may be employed for carburetting purposes. Both coal-gas and water-gas tar have been used.

As can be seen from the diagrammatic sketch (Fig. 339), the plant consists of two identical generators, and no other vessels are used for the production and enrichment of the gas. The generators are lined throughout with fire-bricks, and the fuel sprays pass through the centre of the charging-door lids. In order to thoroughly grasp the principle of the system, it is essential that the functions of the various connexions on the generators should be understood. Near the top of each generator is a tube connecting the two shells, and by means of this the gas produced in one generator may pass to the other. In addition, both generators are fitted with primary and secondary air supplies from a central blast pipe. The primary air inlets are below the fire-bars, whereas the secondary air is admitted at a point on a level with the top of the fuel bed. There is a gas outlet to each generator. These are below the fire-bars, and they split up into a two-way pipe, one branch of which leads to a stack-pipe, the other passing to a hydraulic main which connects the generator to the cooling and washing apparatus. Each generator is fitted with a steam supply, the steam being introduced beneath the fuel bed, in the usual way.

The apparatus is started in the same way as the ordinary water-gas plant; that is, a wood fire is first kindled and the coke bed is gradually built up on this. When the fires in both generators are thoroughly started, and the coke is on a level with the secondary air inlets, the air-blast is admitted below the fuel in (say) the right-hand generator and above the fuel in the left-hand generator. For the sake

of simplicity in describing the operations, it will be of advantage to designate the right-hand generator as No. 1, the left-hand being No. 2.

Before blowing is commenced, the stack-valve on No. 1 generator is, of course, shut, whereas that on No. 2 generator is opened. In this way, the direct air-blast raises to a certain extent the temperature of the fuel bed in No. 1 generator, but, as combustion is incomplete, a stream of producer gas is passing through the top connecting tube into the second generator. This combustible gas then comes into contact with the secondary air-blast, and its consequent combustion provides sufficient heat for raising the temperature of the fuel in this generator. The hot gases pass downwards through the coke bed, and then away through the open stack valve.

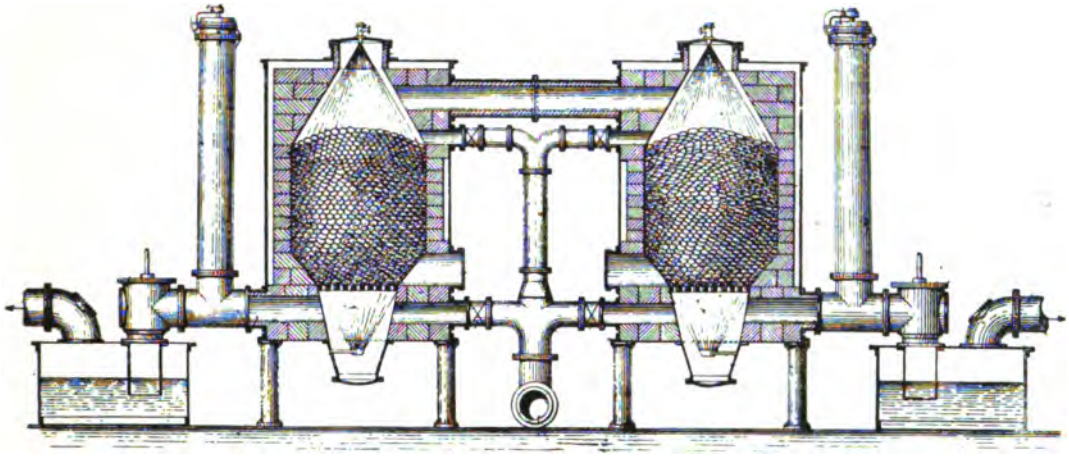


FIG. 339.—THE "RINCKER-WOLTER" WATER-GAS PLANT.

It is advisable to secure, as far as possible, nearly equal temperatures in both vessels, and in order to do this the sequence of generators is reversed after a period of about two minutes. Thus the primary blast is admitted to No. 2 generator, and the producer gas meets with the secondary air in the top of No. 1.

By heating the generators in this way for some time a temperature sufficiently high for gasmaking is obtained.

CYCLE OF OPERATIONS

In the Rincker-Wolter plant the gasmaking "run" usually lasts for about six minutes, but it is unique in that no steam is admitted to the generators during the first half of the period. Before the "run" is commenced, the various air valves and flue dampers are necessarily closed and a passage is made for the gas by opening the valve at the outlet of the hydraulic main or "dipper." The generators are, of course, always operated in series for "blowing," whilst gasmaking is carried on in each one alternately. Assuming that a "run" has just commenced in No. 1 generator, then the oil, or other carburetting agent employed, after passing through a meter, is sprayed on to the coke in this generator.

On coming into contact with the incandescent coke, the oil is immediately gasified, and passes off through the bottom of the generator to the hydraulic main, where the tarry matter and particles of carbon are retained. At the expiration of about three minutes, the oil is shut off and steam is blown through the same spray —partly for cleaning purposes—for a period of about seventy-five seconds. The No. 1 " dipper " valve is then closed, the corresponding valve on No. 2 being opened. Steam is then injected under the fire-bars of No. 1 generator for one minute, and the gas produced passes through the connecting pipe and second fuel bed to the opposite hydraulic main. The steam is now shut off, and gives way to a blast of air, which is continued for a few seconds, and thoroughly scours the apparatus.

From the above description, it may appear that a somewhat complicated series of operations are comprised in the " run." The cycle is, of course, more or less intricate when compared with the water-gas systems in common use in this country. It will easily be grasped, however, by tabulating the working as follows :—

Oil sprayed in (say) No. 1 generator.	3 minutes.
Steam blown through spray	75 seconds.
No. 1 " dipper " valve closed and No. 2 " dipper " opened.	
Steam admitted under fire-bars of No. 1.	1 minute.
Air admitted to No. 1	about 10 seconds.
Total period of " run"	about 6 minutes.

After the completion of the above " run," the blowing cycle, as previously described, commences, and continues for about two minutes. The " run " is then resumed, but with the difference that the first generator in the preceding cycle now becomes second in the sequence. This alternate operation of the generators causes practically similar working conditions for both vessels as regards temperature and consumption of coke and oil.

THE INDUSTRIAL USES OF WATER GAS

In addition to being used as an auxiliary to coal gas, blue water gas has within recent years been applied, with very satisfactory results, to the welding of plates and heating of furnaces and forges. This method has proved of great practical advantage in welding tubes for gas, water and steam mains, for boiler work and also for melting steel. Tests conducted by the Admiralty show the strength of a " blue " gas weld to be equal to that of the plate. Having a very much higher calorific power than producer or suction gas, " blue " water gas may be used for driving gas-engines, the consumption being about 35 cubic feet per B.H.P. hour. The consumption of ordinary suction gas is about 80 cubic feet per B.H.P. hour. No water gas, however, is entirely satisfactory when used for power, for the large proportion of hydrogen prevents high compression in the cylinder of the engine.

By far the most important property of " blue " gas is its exceedingly high flame temperature. Dr. Roessler has found that by admixture with heated air a temperature considerably above the melting point of platinum may be easily obtained. Under general conditions, however, the temperature of the hottest part

of the flame is about 2,800° to 3,000° Fahr. It is owing to this property that "blue" gas is applicable to such processes as welding and forging, and for use in furnaces.

In all processes of the above kind, there is no necessity to purify the gas from sulphuretted hydrogen—merely an ordinary water-scrubber is used. It is, in fact, an advantage to leave the gas unpurified, for it then has a distinct smell, and any escape may be quickly perceived. Thus one of the greatest drawbacks to "blue" gas—its freedom from smell—is more or less overcome. In Germany it has in some cases been thought advisable to impart a distinct odour to the gas, by passing it through a heavy hydrocarbon oil, such as mercaptan.

A new process for which water gas may be employed, and one which will probably be largely developed in the future, is that of producing hydrogen. This is done by liquefying or freezing out all the other constituents—the hydrogen, which, of course, liquefies at a much lower temperature, being left behind.

Cement manufacturers are now making use of water gas, which is introduced into the revolving kiln for the finishing-off process, and it is also finding its way into the brick-making industry.

STEAM GENERATION ON GASWORKS

The large and ever-increasing extent to which carburetted water gas manufacture has been adopted in modern gasworks has placed gas authorities amongst the chief users of steam for manufacturing purposes. The importance of this section of the works' equipment warrants a more detailed study than it is possible to include in the present work, and it is proposed only to consider broadly the more important factors which usually govern the selection, lay-out, and operation of steam generating plant.

SELECTION

The principal factors which usually determine the type of boiler selected are unit evaporative capacity for a given floor space, where this is an important consideration; but in a lay-out for a new works more importance would be attached to convenience of handling fuel and ash, arrangement of main flues, and provision for spare plant and extensions. Steam generating plant is usually designed and rated on the assumption that some kind of natural coal fuel will be the staple fuel used, and the influence of coke or breeze (which may be taken as the staple solid steam raising fuel of the gasworks) on the steaming capacity of the boilers has to be borne in mind in making a selection.

TYPES OF GENERATORS

Broadly, there are in present use two types of boilers, each having their special features, namely, the water-tube or externally fired boiler, typified in the Babcock and Wilcox pattern, and the fire-tube or internally fired Cornish and Lancashire types. When capacity and limited floor space are the chief factors, the range of selection is limited to the various patterns of the former type, which have usually a ratio of heating surface to grate area of 50 or 60 to 1, as compared with about 25

to 1 available in the Lancashire type. For rapid steaming and quick response to sudden heavy demands, the water-tube boiler is now recognized as the more sensitive, but the greater steam and water reserve capacity of the Lancashire type boiler renders it the more suitable for the intermittent heavy pulls of the water gas plant. To realize the advantages of both types a combination battery working in parallel has been found to be most effective in responding to the severest conditions imposed. In the matter of thermal efficiency there would appear to be little, if any, in favour of either type.

GRATE AREA

The economic rate of combustion of fuel and the area of the boiler fire-grates determine the normal evaporative capacity. With coke as fuel, 22 lbs. to 25 lbs. per sq. ft. of grate area per hour represent the economic average maxima for hand-fired fixed grates. Higher rates may, of course, be attained, but only at the expense of efficiency. Probably 18 lb. to 20 lb. would represent the best normal working rate for average coke or breeze. The limiting factor in grate area in the Lancashire type boiler is the length of grate which a man may efficiently stoke and clinker, usually 6 ft. 6 ins. to 7 ft. 6 ins., measured from the furnace front. This factor limits the total effective area to 36 or 38 sq. ft. in the larger capacity boilers of this type. Now, assuming evaporative values for coke and breeze respectively of 9 lb. and 5 lb. of steam per lb. of fuel, as fired, the steaming capacity at the various rates of firing indicated may be accurately arrived at. To the gas engineer, the relatively large proportion of grate area obtainable in the water-tube boiler is certainly an attractive feature, having in mind the characteristics of the staple fuel.

DRAUGHT

Except perhaps where an existing chimney shaft provides the necessary draught, some system of impelled draught may be "induced" or "forced," *i.e.*, by means of an exhaust fan located near and discharging into the chimney shaft; or a pressure fan applied to the under-side of the fire-grate. The induced system depends upon the maintenance of a partial vacuum over the fire, but possesses the disadvantage of increasing the cold air infiltration through the brickwork setting, etc., while it tends, by increasing the speed of the waste gases, to carry over and discharge at the chimney a portion of the grit and dust, which, with the "forced" system properly applied, remains on the grate or falls immediately beyond the bridge wall or first baffle. The various types of steam-jet forced draught furnaces, with one or more short chimney shafts of large area, are among the most favoured systems now adopted. The height to which the boiler shaft is carried, and consequently the cost of construction, will be largely determined by the system of draught adopted, whether "natural," "induced," or "forced." The apparently beneficial effect of a limited supply of steam on the combustion of coke warrants due consideration of the steam-jet impelled system, applied either on the closed ash pit or hollow fire-bar principle.

Various types of steam-jet forced draught furnaces, permitting a comparatively short chimney shaft to be used, have been employed in conjunction with coke and

breeze burning for some years, but in many cases the alterations have been cumbersome and expensive. The latest blower, introduced by the London Coke Committee, may best be described as providing an "impelled" draught, which is admitted beneath the fire bars by either two or three delivery pipes fashioned somewhat on the lines of a Venturi tube. The whole can be fitted to a coal-burning boiler in a

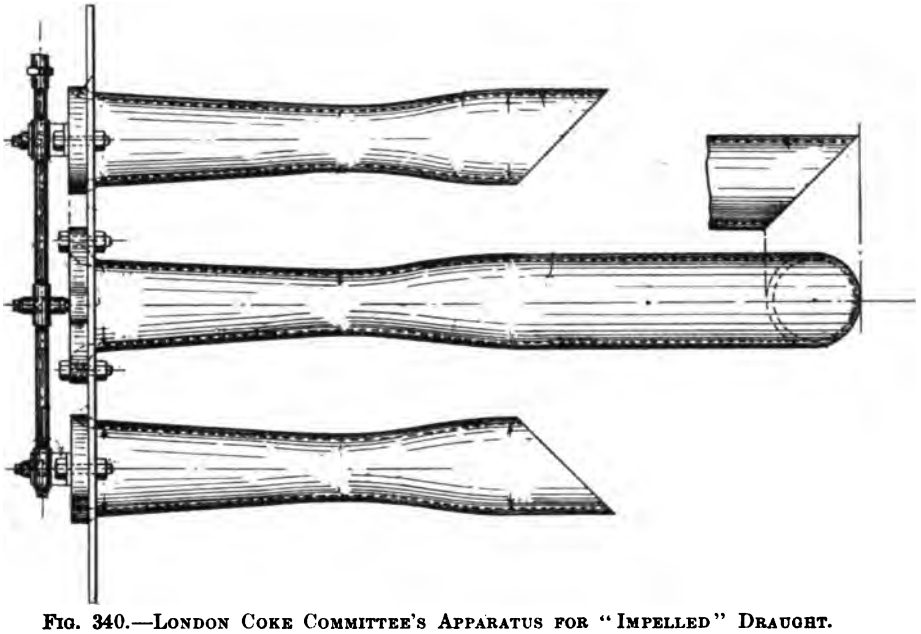


FIG. 340.—LONDON COKE COMMITTEE'S APPARATUS FOR "IMPELLED" DRAUGHT.

few hours, and requires for its operation only two to three per cent. of the steam raised.

MECHANICAL STOKING

In the larger works the possibility of automatically stoking and cleaning boiler furnaces has led to the adoption of mechanical stokers of the travelling-grate or "sprinkler" type. The latter are applicable to either water-tube or Lancashire boilers, but so far the application of the travelling-grate of the "underfeed" or Babcock type has been limited to water-tube boilers of fairly high capacity. These generally operate in conjunction with some system of forced draught. Rates of 30 lb. of fuel per square foot per hour are said to be maintained, so that the full normal capacity of the boiler with this equipment may be realized with coke fuel.

SUPERHEAT

All steam engines are essentially heat engines, and the manufacture of water-gas is essentially a heat process. Accordingly, the use of steam superheaters, either as an integral part of the boiler unit or separately fired, is the trend of modern practice.

ECONOMIZERS

The development of the economizer has followed the recognition of the inefficiency of coal as a boiler fuel, with which fuel as much as 20 per cent. saving may be effected by installing a suitably proportioned economizer between a coal-fired boiler and its chimney shaft. The same would not, of course, apply in the case of coke-fired boilers, in which the heat of combustion appears to be largely transmitted to the water and steam inside by radiation, and consequently there is a smaller proportion of heat carried off in the waste gases. Moreover, as the proportion of excess air necessary for the complete combustion of coke is so much less than that required with coal, a relatively smaller volume of gas comes in contact with the economizer tubes. Reliable tests show that where an average increase of 108° Fahr. in feed temperature was obtained with a coal-fired boiler fitted with an economizer of the ordinary type, an average increase of only 78° Fahr. was maintained when the same boiler was working with coke fuel on a forced draught grate. For each 10° Fahr. increase in feed temperature, a saving in fuel of about one per cent. is effected, so that it would appear to be somewhat problematical whether the initial cost and maintenance of economizers would be justified when coke or breeze is used as the fuel.

APPROXIMATE FUEL COST OF EVAPORATION FROM AND AT 212° FAHR.

(Compiled by E. W. L. Nicol)

COAL SLACK.		HARD STEAM COAL.		SMOKELESS WELSH COAL.		GAS COKE.	
Mechanically stoked.		Hand fired : Natural Draught.		Hand fired : Natural Draught.		Hand fired : Forced Draught.	
At per ton.	Evaporative value. 7·5 lb.	At per ton.	Evaporative value. 9·5 lb.	At per ton.	Evaporative value. 10·5 lb.	At per ton.	Evaporative value. 9 lb. net.
	per 1,000 gallons evaporated.		per 1,000 gallons evaporated.		per 1,000 gallons evaporated.		per 1,000 gallons evaporated.
s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.
7 0	4 2	14 0	6 6	16 0	6 11	13 0	6 5
8 0	4 8	15 0	7 0	17 0	7 4	14 0	6 11
9 0	5 4	16 0	7 6	18 0	7 9	15 0	7 5
10 0	5 11	17 0	7 11	19 0	8 1	16 0	7 11
11 0	6 6	18 0	8 5	20 0	8 6	17 0	8 5
12 0	7 1	19 0	8 11	21 0	8 11	18 0	8 11
13 0	7 8	20 0	9 4	22 0	9 4	19 0	9 5
14 0	8 4	21 0	9 10	23 0	9 9	20 0	9 11
15 0	8 11	22 0	10 4	24 0	10 2	21 0	10 5
16 0	9 6	23 0	10 9	25 0	10 7	22 0	10 11
17 0	10 1	24 0	11 2	26 0	11 0	23 0	11 5
18 0	10 8	25 0	11 8	27 0	11 5	24 0	11 11
19 0	11 4	26 0	12 2	28 0	11 10	25 0	12 4
20 0	11 11	27 0	12 8	29 0	12 4	26 0	12 10
21 0	12 6	28 0	13 1	30 0	12 9	27 0	13 5
22 0	13 1	29 0	13 7	31 0	13 2	28 0	13 11
23 0	13 8	30 0	14 0	32 0	13 7	29 0	14 5
24 0	14 4	31 0	14 6	33 0	14 0	30 0	14 10
25 0	14 11	32 0	15 0	34 0	14 5	31 0	15 4
26 0	15 6	33 0	15 6	35 0	14 10	32 0	15 10
27 0	16 1	34 0	16 0	36 0	15 4	33 0	16 4
28 0	16 8	35 0	16 5	37 0	15 9	34 0	16 10
29 0	17 4	36 0	16 11	38 0	16 1	35 0	17 4
—	—	—	—	39 0	16 6	—	—

N.B.—The average evaporation of a Lancashire boiler is about 500 gallons per hour.

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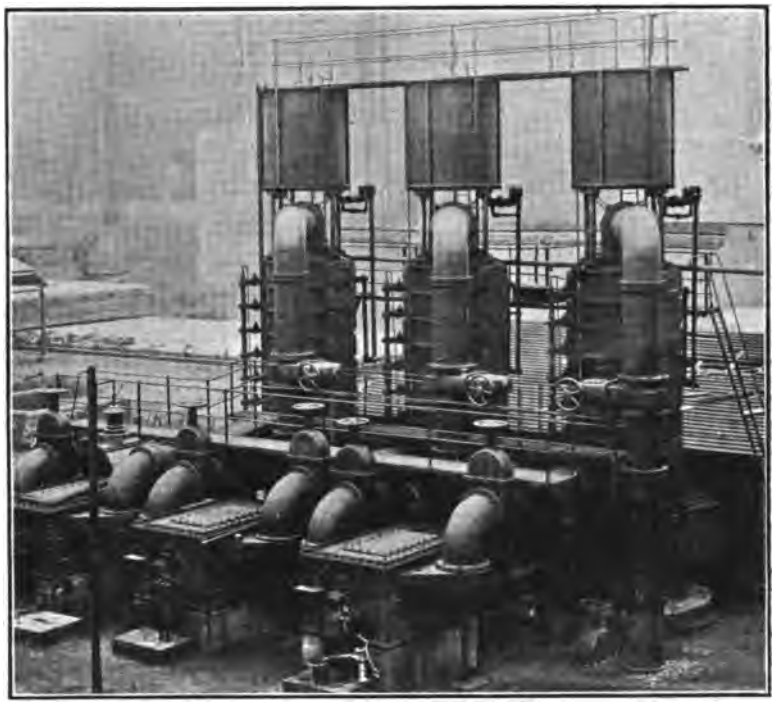

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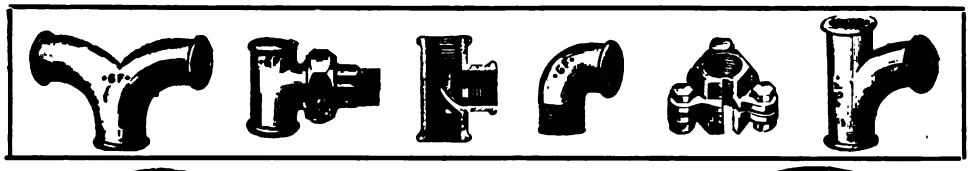

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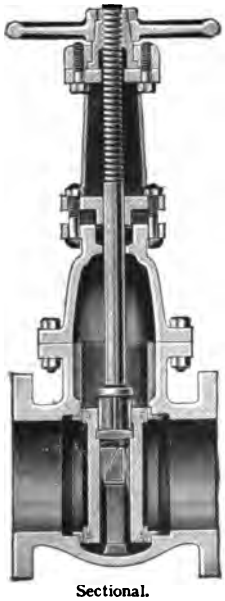

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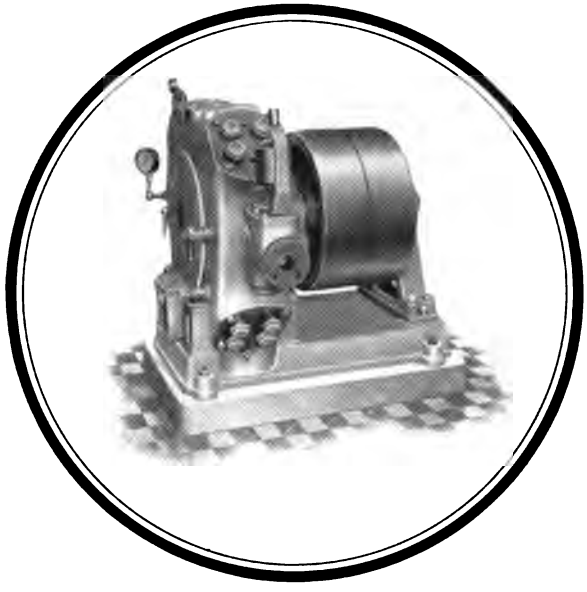

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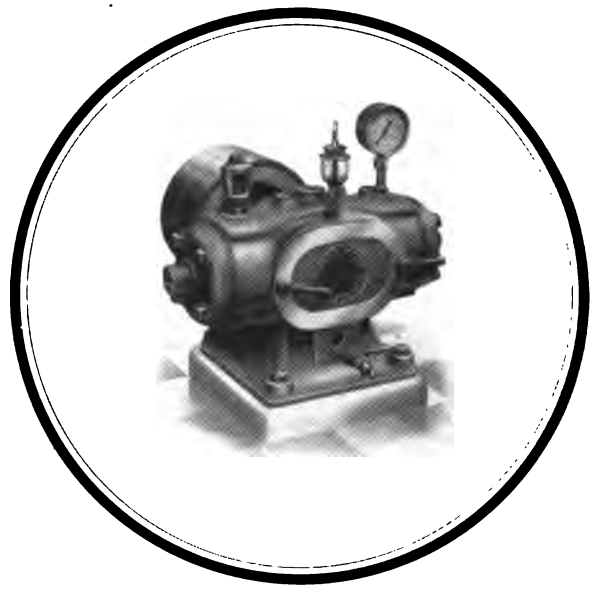

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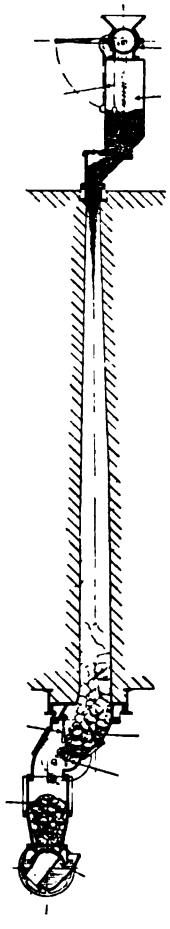

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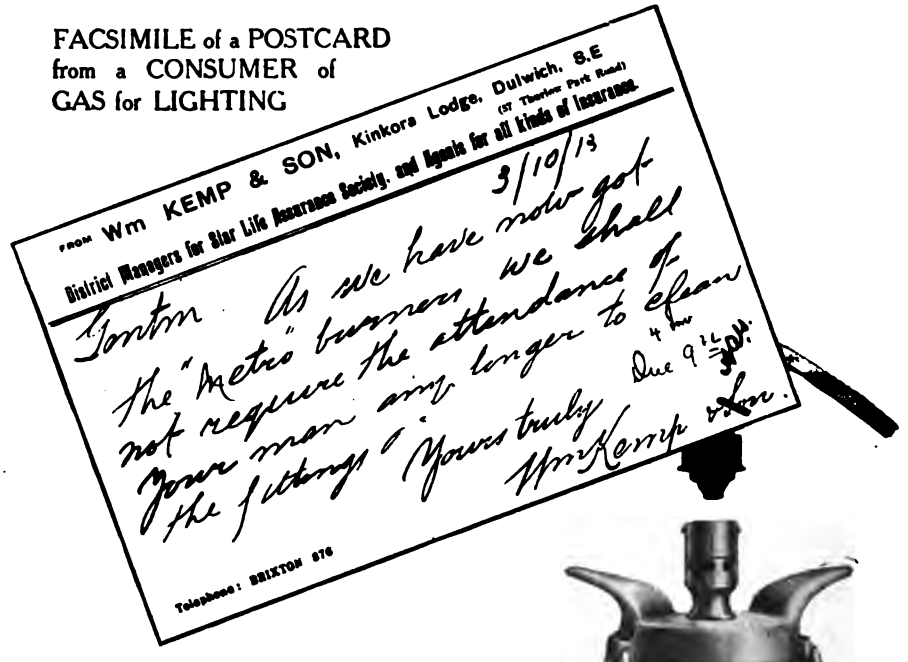
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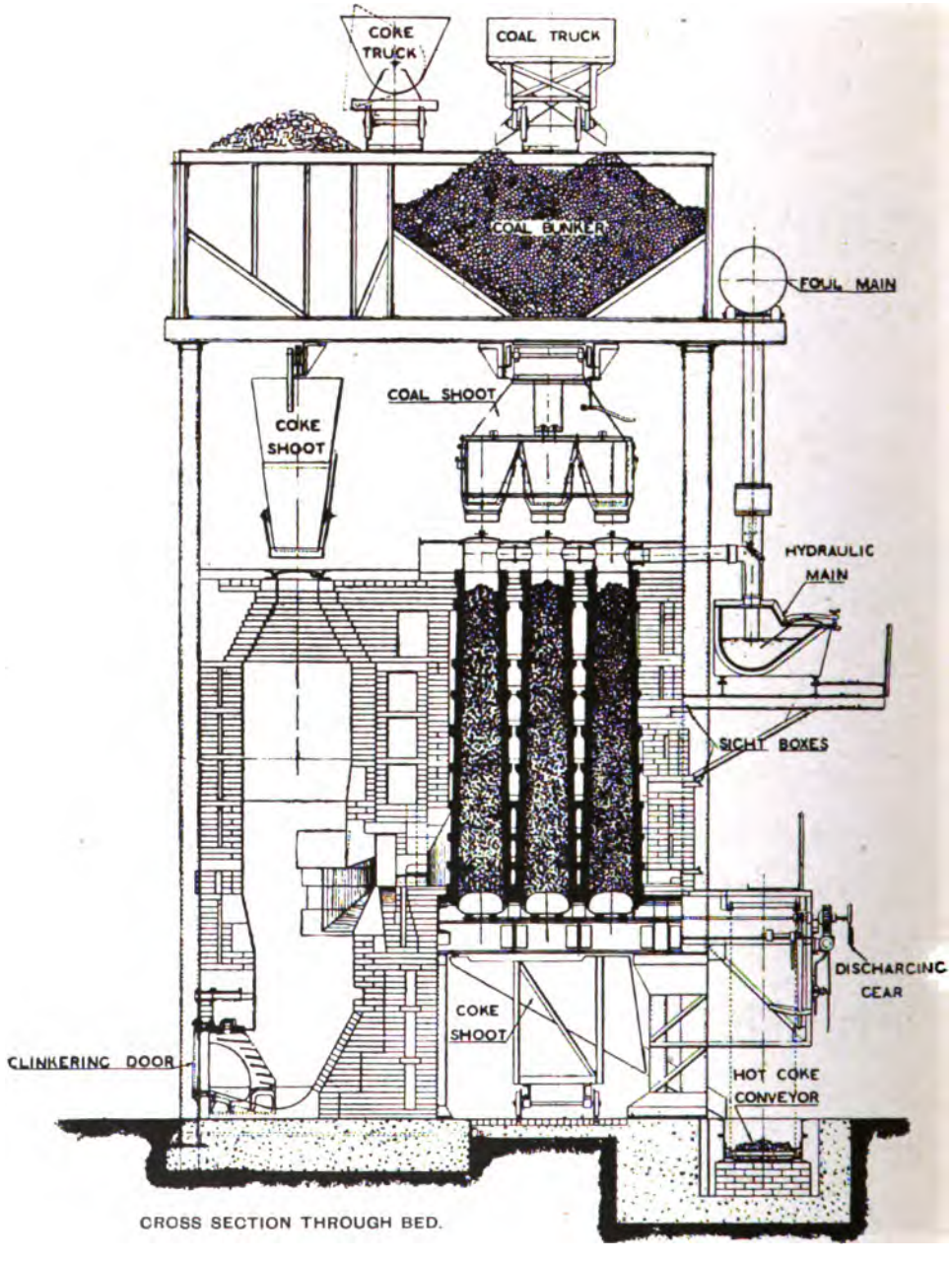

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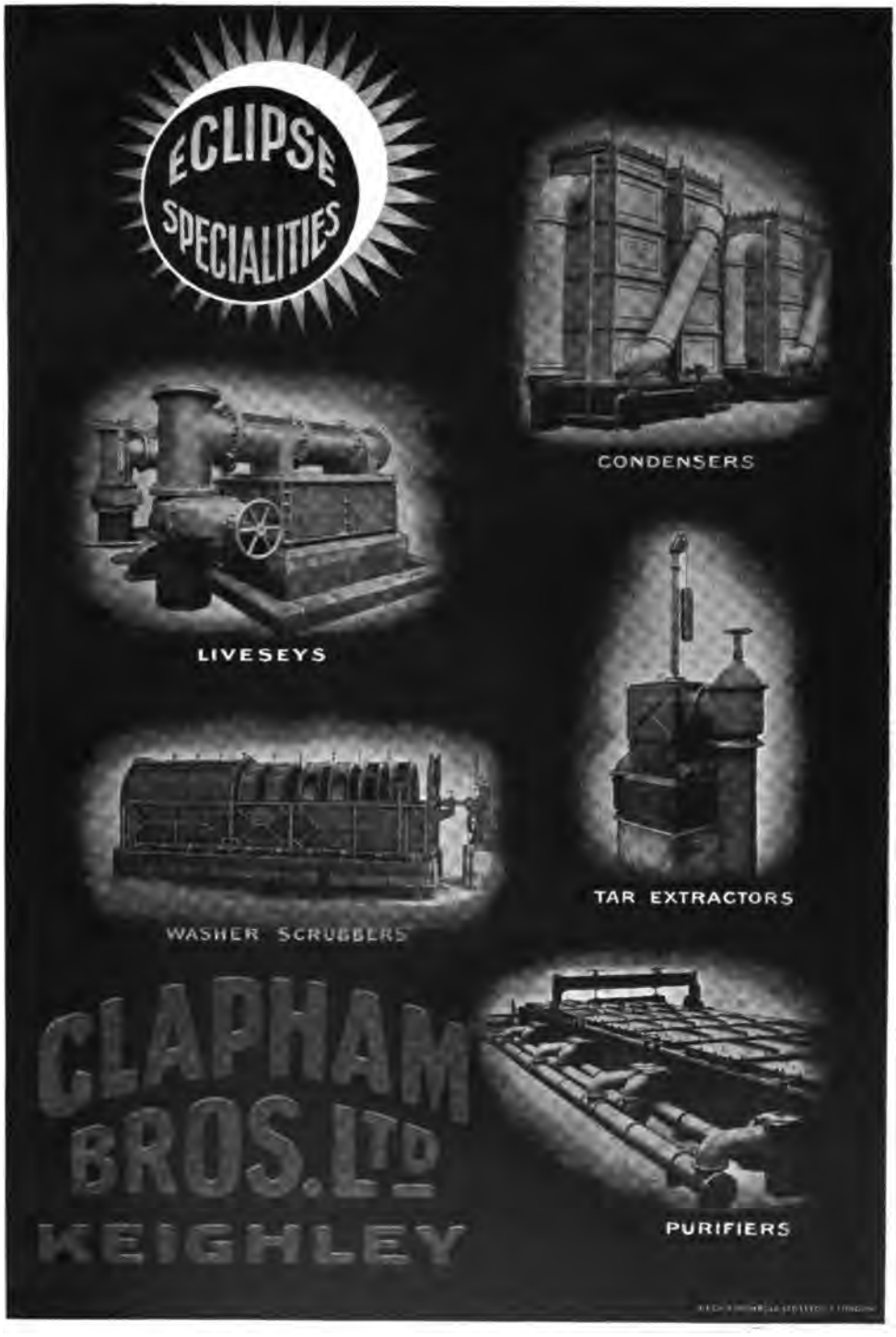
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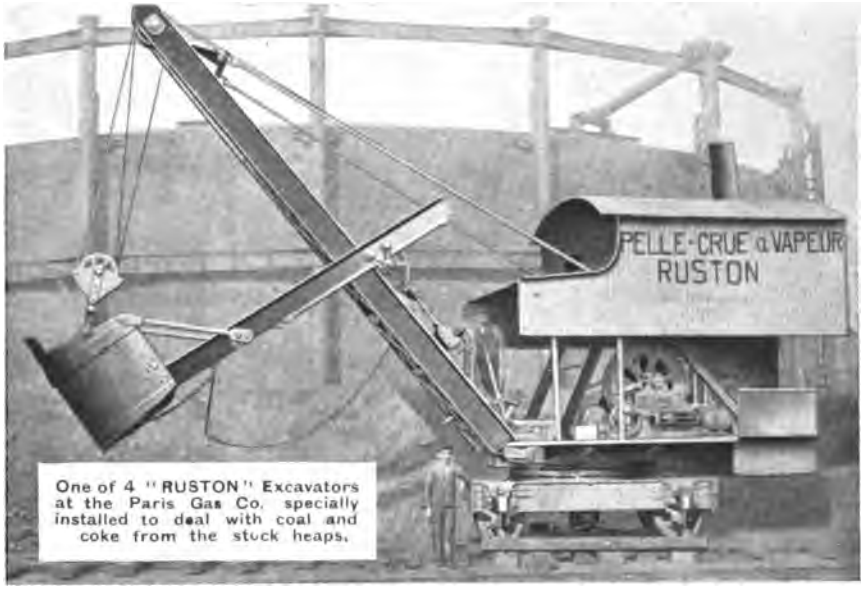

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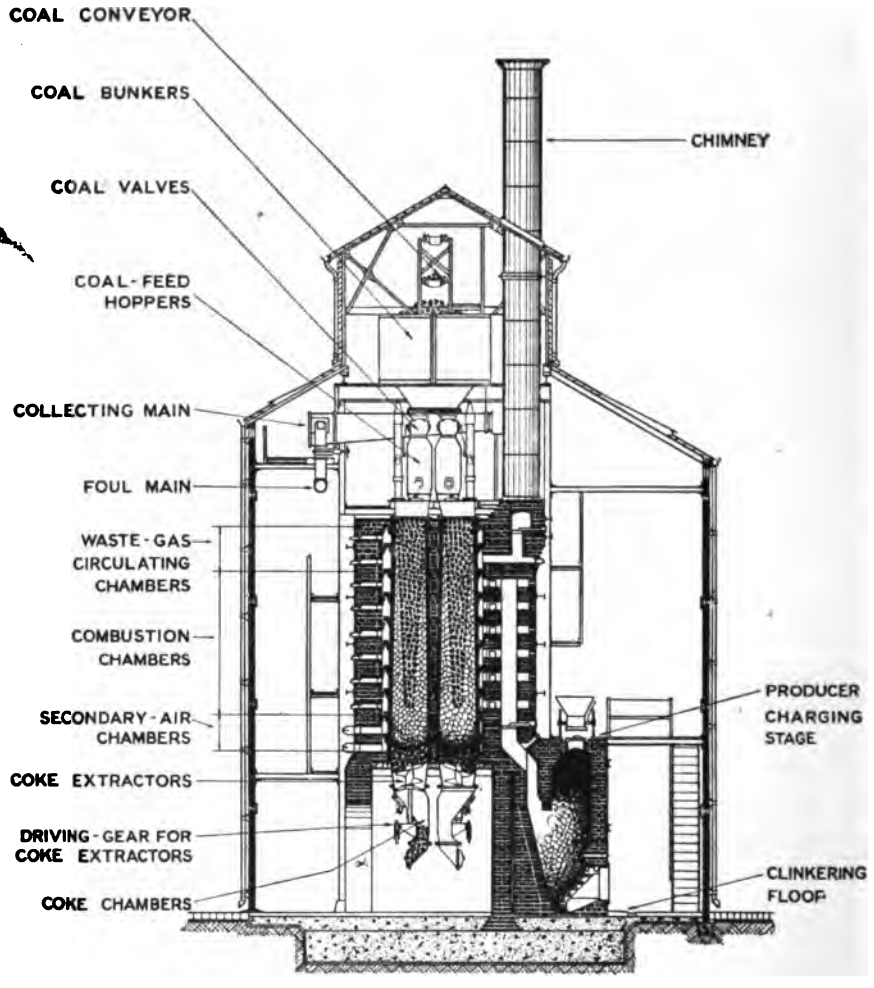

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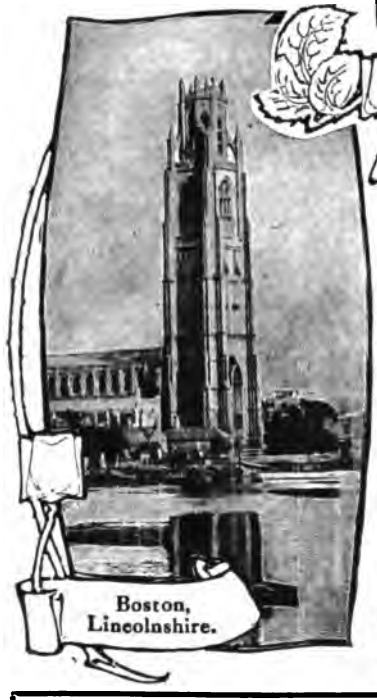

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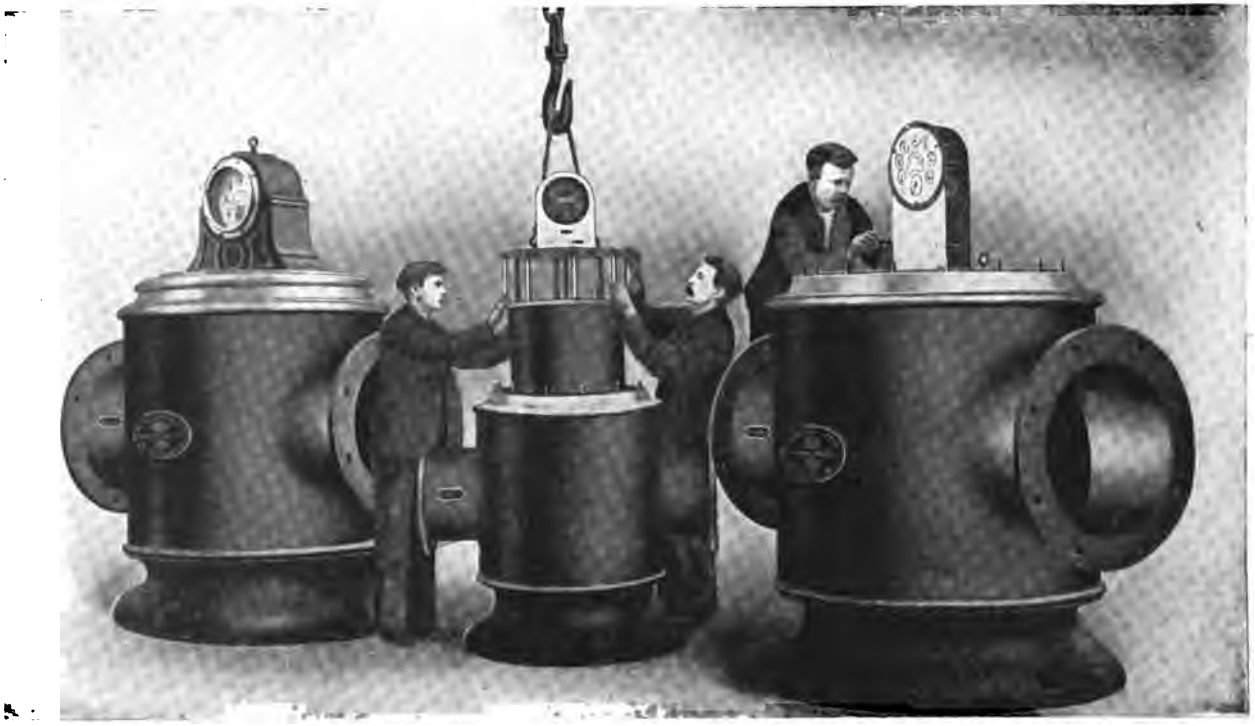

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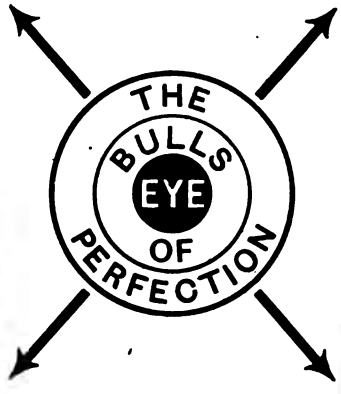

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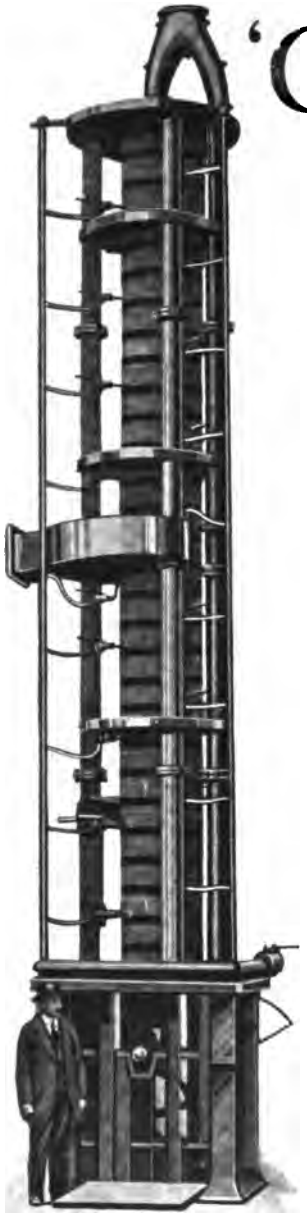

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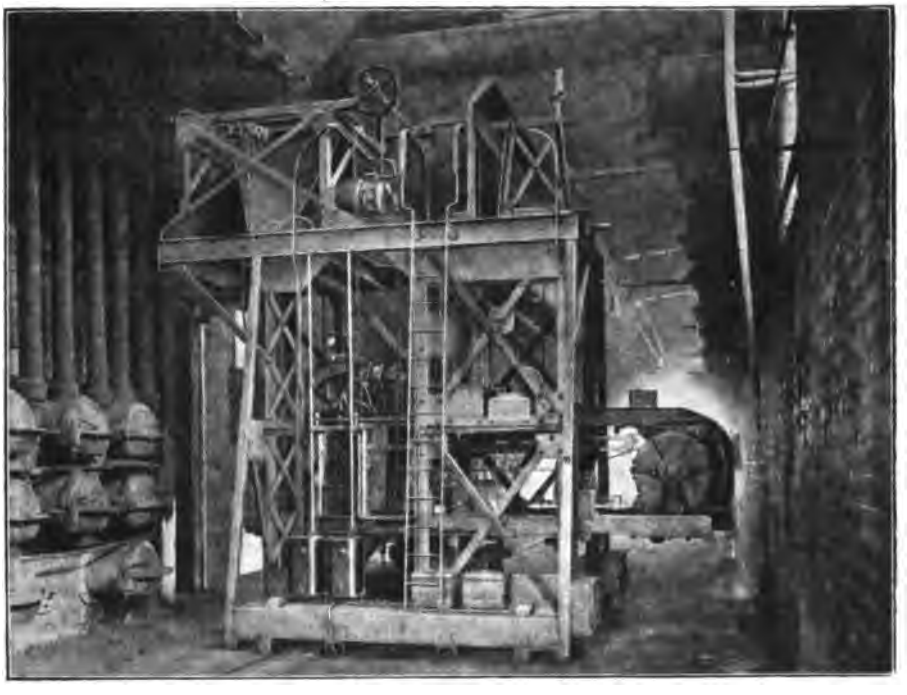

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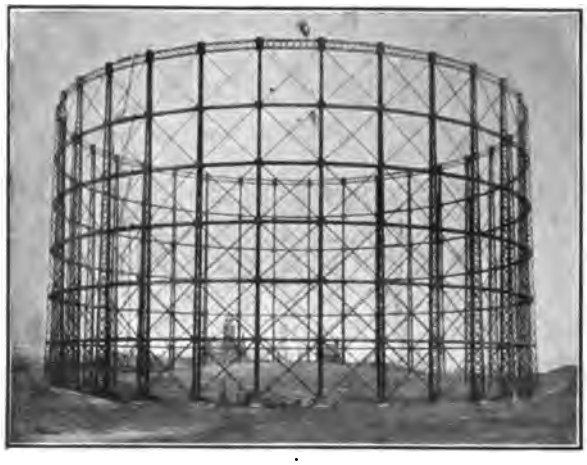

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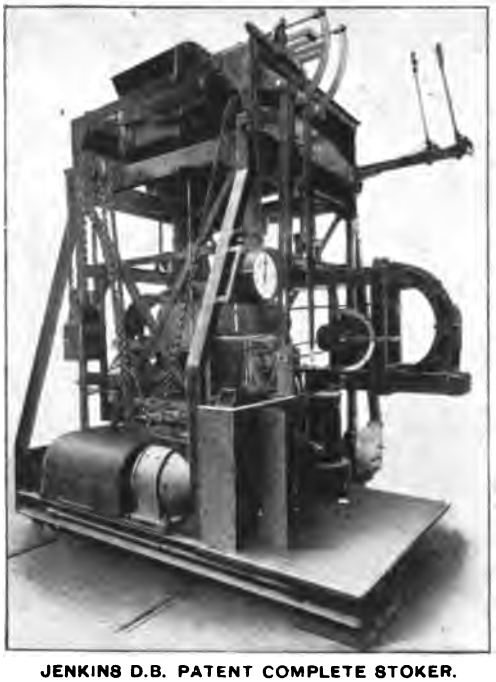

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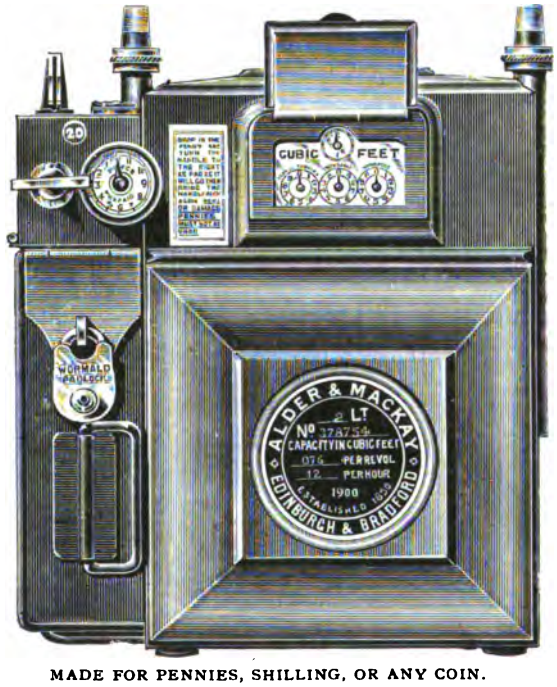

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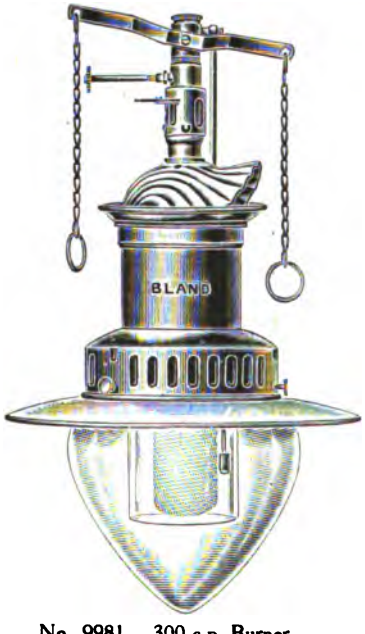

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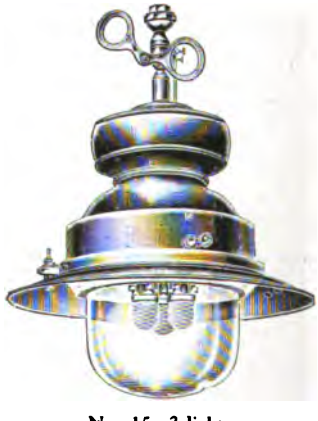

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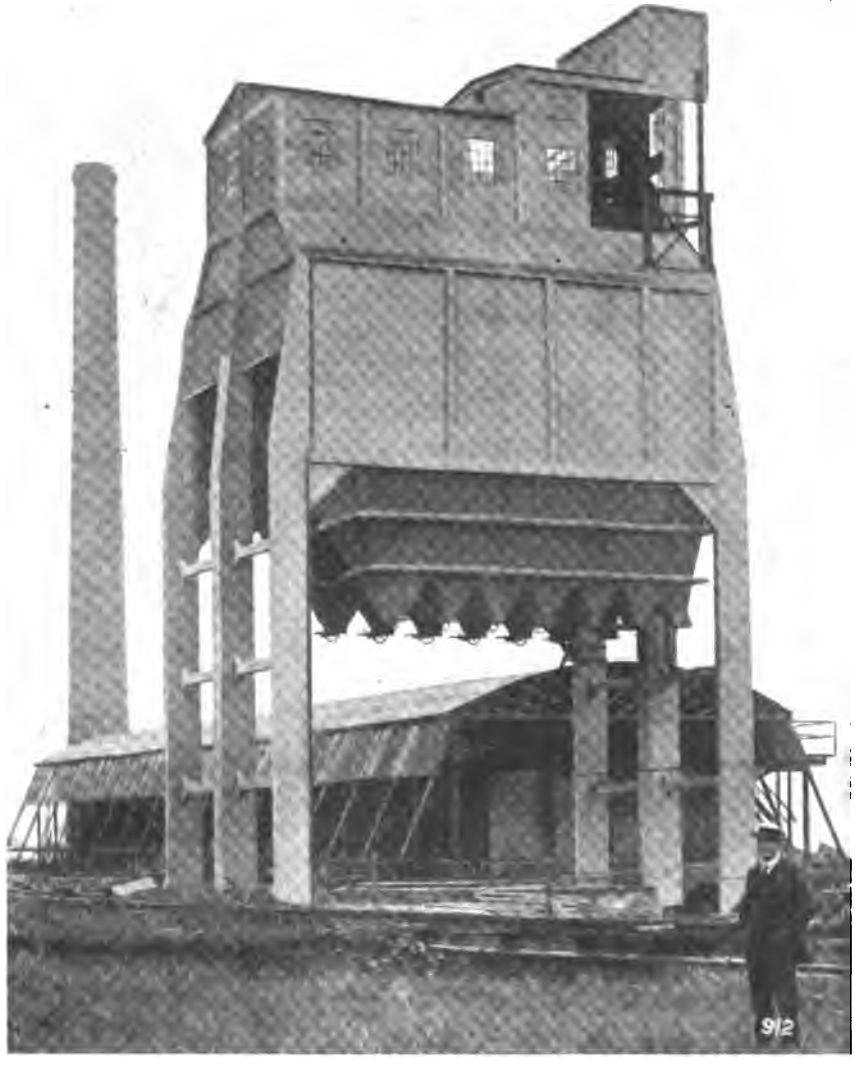

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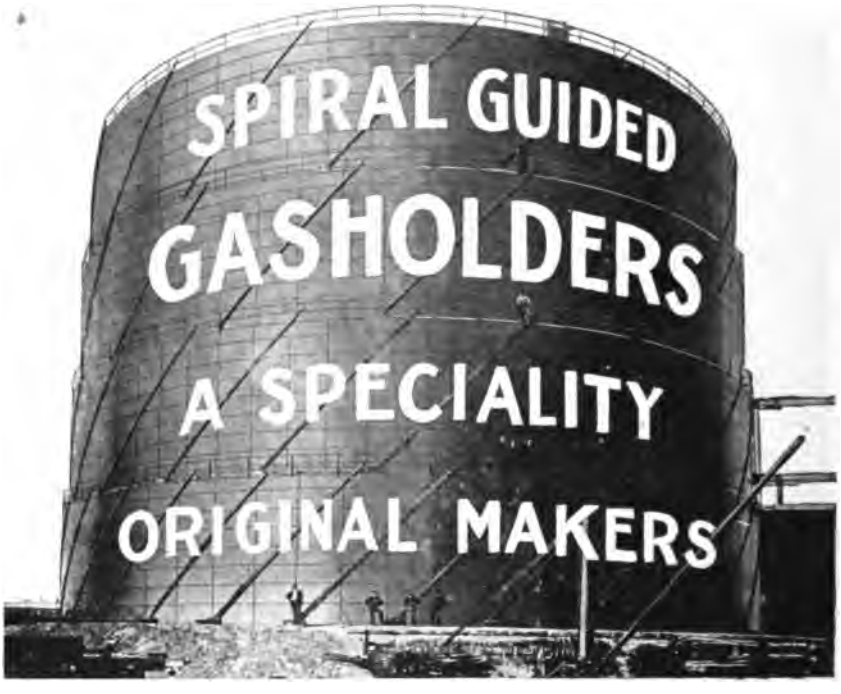

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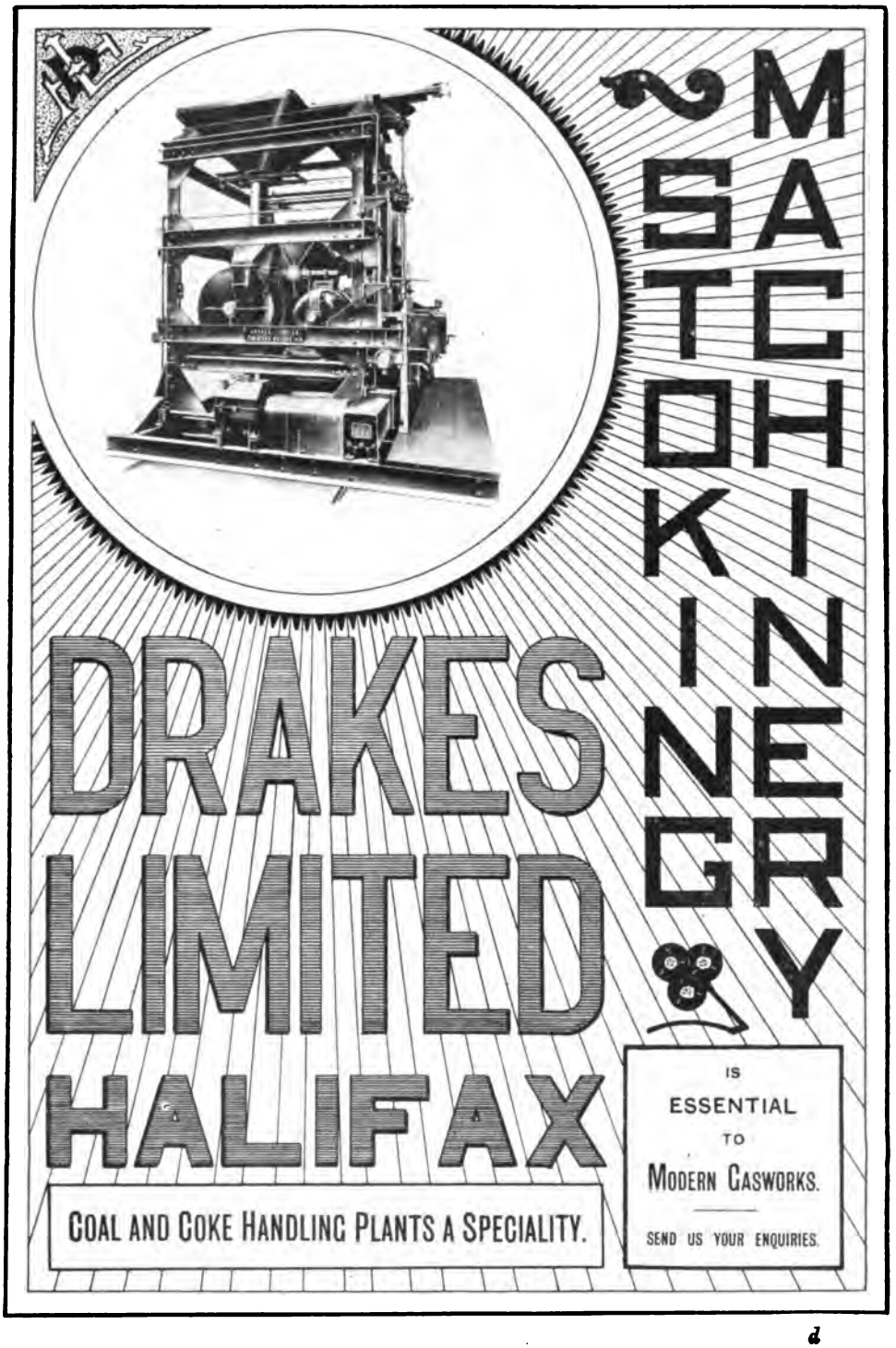
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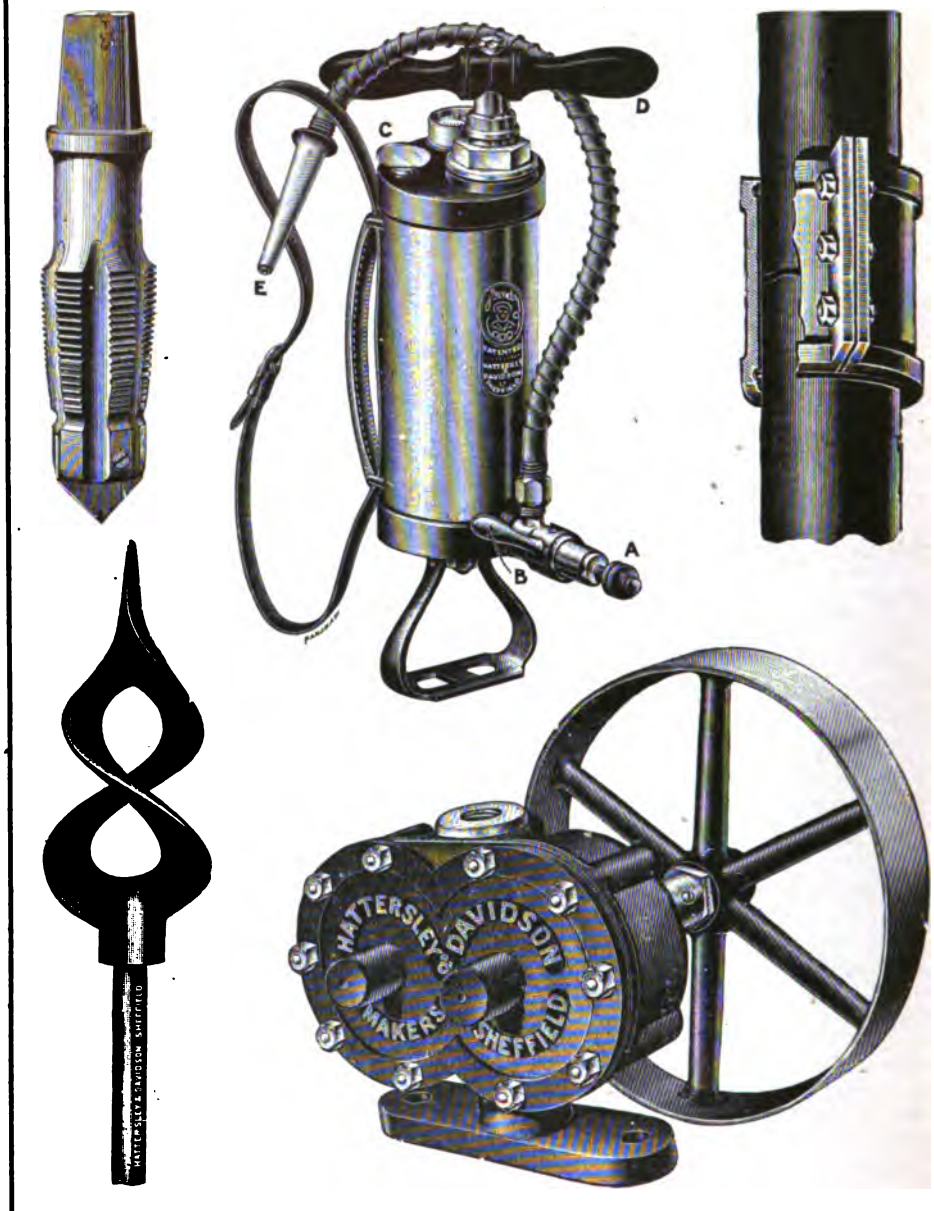

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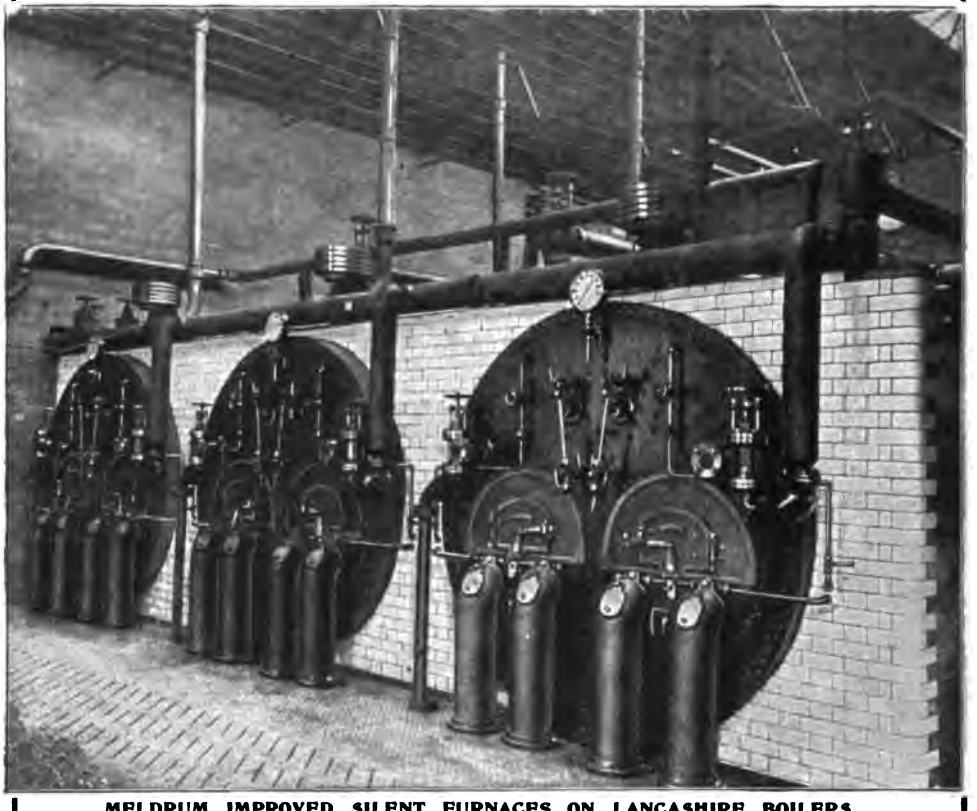

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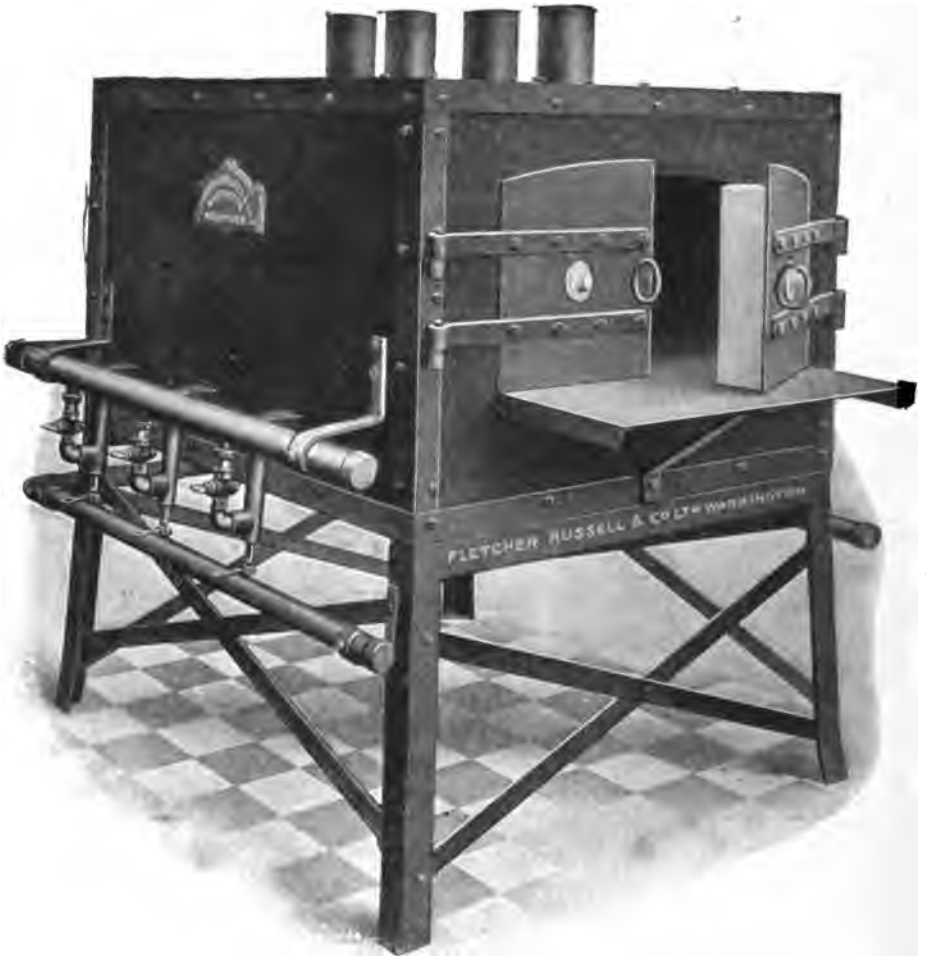

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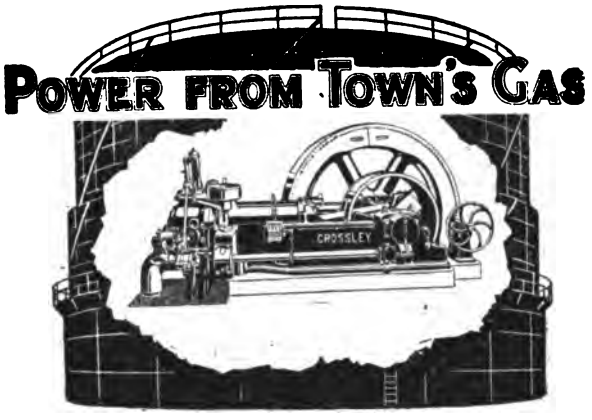

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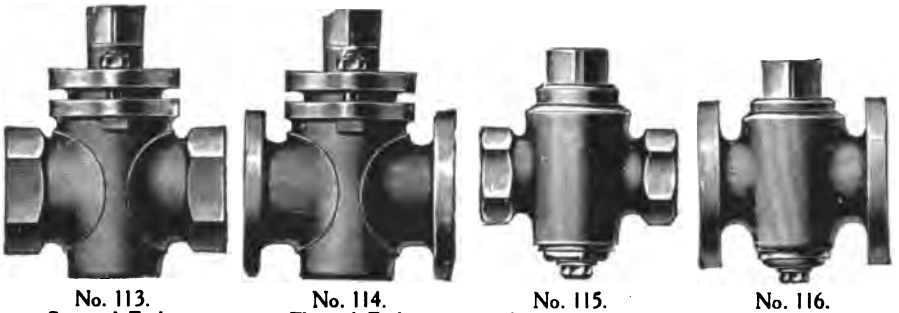

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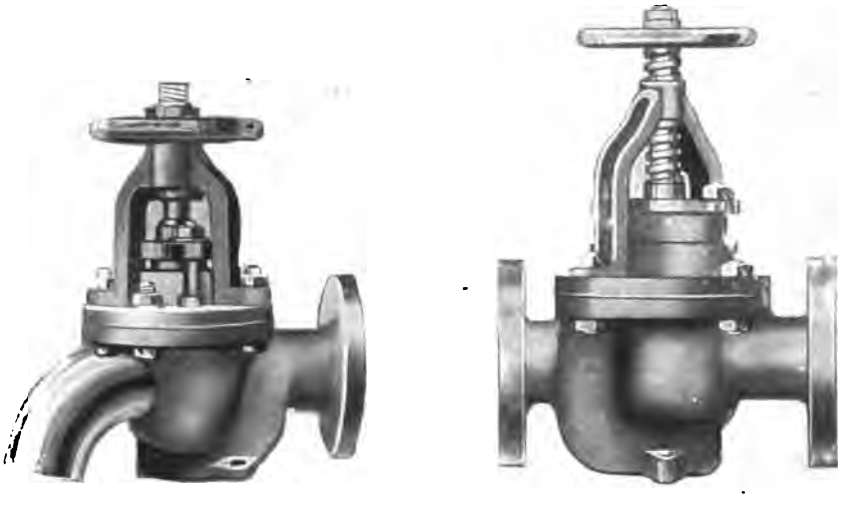

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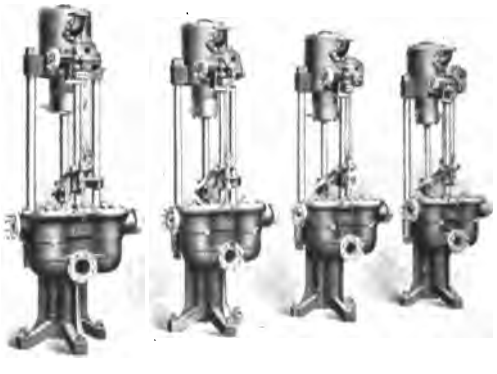

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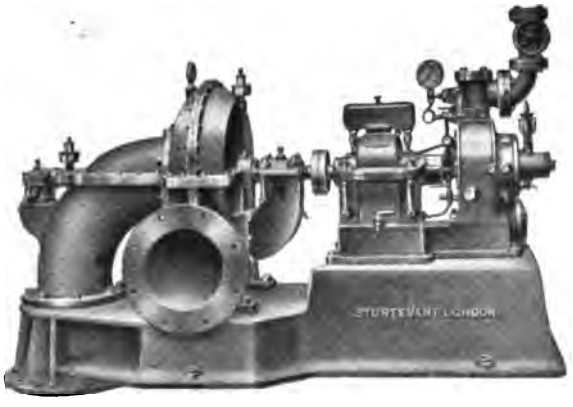

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